DEVELOPMENT OF TESTING PROTOCOLS AND EVALUATION METHODS FOR EROSION AND SEDIMENT CONTROL PRODUCTS

BY

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THESIS

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ABSTRACT

A study at the Erosion and Sediment Control Research and Training Center (ESCRTC) at the University of Illinois at Urbana-Champaign was conducted to develop testing protocols for ditch checks and erosion control blankets, as well as evaluate the products' effectiveness as erosion and sediment control best management practices (BMPs) for construction sites. Construction activities generally involve significant land disturbances, leaving the soil unprotected and more susceptible to erosion, which may in turn adversely affect the surrounding environment.

The lack of quantitative and qualitative data on erosion and sediment control product performance using standardized evaluation methodologies under locally relevant climate and soil conditions makes it difficult to appropriately select the most suitable erosion and sediment control BMPs. This study details evaluation protocols for ditch checks and erosion control blankets, as well as product evaluations under easily replicable conditions.

For sediment control, three ditch check products (Sediment Logs, Triangular Silt Dike and GeoRidge) were evaluated and their results were compared using the testing protocol described in this study under different flow conditions. The results obtained revealed that the Triangular Silt Dike product performed significantly better than the other two products tested, while GeoRidge performed better than the Sediment Logs for higher flows and similarly for medium and low flow rates. For erosion control, three erosion control blankets (SC-150, DS-75 and Curlex I) were evaluated along with a bare control plot, and their results were compared and discussed. The results of the erosion control blanket experiments revealed that these products are an efficient control measure to ameliorate the effects of erosion and sediment transport on disturbed lands. The results shown a big variability of runoff collected when the Curlex I was

installed relative to the other two treatments and the control plot. This variability was due to the dryness of the soil when the CurlexI was being evaluated even though the erosion plots were wetted prior to product evaluation to overcome the possible effects of soil dryness during the products evaluation. On the other hand, and regardless the total amount of runoff collected, the three blankets evaluated presented similar sediment concentration in the samples collected during testing, and significantly smaller than the sediment concentration obtained from the control plot.

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CHAPTER 1

INTRODUCTION

Construction activities generally entail earthmoving operations that involve substantial disturbance of topsoil and vegetative cover. As a result, stormwater runoff and erosion rates are significantly increased. The sediment runoff rates from construction sites are typically 10 to 20 times greater than those from agricultural lands (EPA, 2000).

On 1 December 2009, the EPA published effluent limitations guidelines (ELGs) and New Source Performance Standards (NSPS) to control discharge of pollutants from construction sites. As of 1 August 2011, construction sites that involve land disturbance of over 20 acres at a time were required to comply with the new turbidity requirements (280 NTU), and from 2 February 2014, the limitation will also apply to construction sites disturbing 10 acres or more at a time.

These actions demonstrate efforts to improve effluent quality by adopting the necessary BMPs, implementing proper stormwater management, and using available technology to reduce pollution of water bodies. The lack of information on ditch check and erosion control product performance under standardized testing and evaluation protocols creates difficulties for engineers, designers, and installers in choosing appropriate technologies to mitigate pollution from construction areas. Performance data is often difficult to compare and interpret due to differences in testing conditions and evaluation procedures. Additionally, data available for sediment retention performance and effluent quality is frequently incomplete or partial.

This study is intended to develop and implement evaluation criteria and testing protocols for erosion and sediment control products under Illinois weather and soil conditions based on prior studies. This study will also provide guidance to the Illinois Department of Transportation

(IDOT) in the installation and maintenance of sediment control devices, as well as providing quantitative data as a resource for assessing whether specific products should be permitted for use in IDOT projects.

CHAPTER 2

OBJECTIVES

The overall objective of this study was to develop reliable evaluation protocols for ditch check and erosion control blanket products of interest to IDOT at the Erosion and Sediment Control Research and Training Center (ESCRTC) field site at the University of Illinois Urbana-Champaign. These protocols were intended to provide a means of erosion and sediment control product evaluation under typical Illinois soil and weather conditions. The specific objectives were:

1. Develop a testing protocol for ditch check products.
2. Evaluate ditch check products of similar characteristics under different flow conditions.
3. Develop a testing protocol for erosion control blanket products for hillslope protection.
4. Evaluate erosion control blankets and their effectiveness in protecting bare soils.

CHAPTER 3

REVIEW OF LITERATURE

3.1 Erosion and Sediment from Construction Sites

Land disturbance caused by human activities, such as construction development or agriculture, involve vegetation removal and topsoil disturbance. As a result, stormwater runoff and erosion rates are significantly increased. The sediment loss rates from construction sites can range from 20 to 200 tons $acre^{-1}$ $year^{-1}$, which is 10 to 20 times greater than those from agricultural lands, and 1,000 to 2,000 times higher than undisturbed forested land (EPA, 2000).

Erosion and sediment transport from construction sites has both onsite and offsite economic effects. Scouring of the foundations of hydraulic structures, roads, or other structures are examples of onsite effects caused by soil erosion. Offsite effects are a result of onsite erosion, as the soil particles detached from the construction site are transported by the erosive agents, such as wind or running water, and deposited over farming land, storage reservoirs, channel beds, rivers, and lakes (Morgan, 1995). Along with economic effects, uncontrolled stormwater runoff from construction activities causes degradation in the aquatic habitat. High sediment concentration reduces the sunlight reaching aquatic plants and clogs fish gills (EPA NPDES), which in turn has adverse effects on other aquatic flora and fauna. Landphair et al. (1997) estimated that erosion from construction activities in the US deposits approximately 3.5 billion metric tons of sediment into water bodies annually.

In the 1970s, sediment was recognized as the primary contamination source of waterways in the United States. As a result, legislation at the federal, state, and local level was followed by the development and implementation of regulations and guidelines to prevent and control erosion and sediment delivery to streams and rivers (Toy, Terrence J. 2002).

Extensive studies have been conducted to quantify the amount of sediment leaving a construction site through transportation by stormwater runoff. The U.S. Geological Survey (USGS) and the Dane County Land Conservation Department evaluated the water quality from two small construction sites (less than 5 acres) from June 1998 to July 1999 in Dane County, Wisconsin. The data collected from this study was used in the formulation of the US Environmental Protection Agency's National Pollution Discharge Elimination System (NPDES) regulations required for construction sites that disturb less than 5 acres. The results of the study indicated that small construction sites can generate large amounts of sediment. Stormwater runoff leaving the construction site was monitored for both construction sites before, during, and after the construction phase. Total Suspended Solids (TSS) during the active construction phase were significantly higher than the TSS concentration monitored prior to the start of construction. After the active construction phase was completed and the sites were seeded and mulched, the TSS concentration diminished considerably. The results from these studies showed the need to develop an effective erosion and sediment control plan even for small construction sites.

3.2 Laws and Regulations

The Clean Water Act (CWA) establishes the basis for quality standards regulating the stormwater discharge of pollutants into the water bodies of the United States. The United States Environmental Protection Agency (USEPA) implements pollution control programs and regulates water quality standards for all contaminants in surface waters.

The EPA's National Pollutant Discharge Elimination System (NPDES) is a Federal program, part of the Clean Water Act, designed to maintain the quality of the nation's surface water bodies. The NPDES controls and regulates the discharge of pollutants into water bodies of the United States, including pollutants associated with construction activities throughout the U.S.

These regulations were initially designed for municipal sewage treatment plants and industrial discharges, and stormwater was not included in the NPDES regulations. After evaluating the water quality impact due to stormwater discharges, the EPA established specific regulation for stormwater in 1987 (R. Pitt et al. 2007).

The EPA published the Phase I rule requiring National Pollutant Discharge Elimination System (NPDES) permits for large municipalities (municipalities with population over 250,000) and certain industries in 1990. The Phase II rule was developed several years later to include medium size municipalities (with a population between 100,000 and 250,000) and other industries. In the Phase I rule, construction activities were included as an industry, and regulations were applied to any construction site exceeding 5 acres of soil disturbance (or less than 5 acres if the construction activity was a part of a larger common plan of development or sale with a planned land disturbance of 5 acres or more). Phase II reduced the land disturbance to 1 acre or more.

In the state of Illinois, the NPDES stormwater program is managed by the Illinois Environmental Protection Agency (IEPA). The IEPA issues the ILR10 permit, which provides the threshold requirements for stormwater discharges from construction site activities. The ILR10 permit authorizes all discharges of stormwater associated with construction activities that involve more than one acre of land disturbance, and construction sites less than one acre that are part of a larger common plan. This permit also authorizes discharges for construction sites where less than one acre of land is disturbed, but that have the potential to violate the water quality standards or provide a significant contribution of pollutants to waters of the state.

To obtain the ILR10 permit, submission of a Notice of Intent (NOI) and Stormwater Pollution Prevention Plan (SWPPP) are required. The NOI must include a description of the project, an approximation of the areal extent of the site to be disturbed, and a certification that a SWPPP will be submitted prior to the commence of the construction activities. The SWPPP must identify potential sources of pollution expected to affect the quality of stormwater discharges associated with the construction site activities. Additionally, the plan must describe the best management practices (BMPs) that will be implemented during the construction activities to reduce the pollutants in the stormwater discharges and ensure compliance with the terms and conditions of ILR10 permit.

On 1 December 2009, the EPA published effluent limitations guidelines (ELGs) and new source performance standard (NSPS) to control discharge of pollutants from construction sites. As of 1 August 2011, construction sites that involved land disturbance of over 20 acres at a time were required to comply with the new turbidity requirements (280 NTU). Beginning 2 February 2014, the limitation will apply to construction sites disturbing 10 acres or more at a time.

3.3 Ditch Check Product Evaluation Protocols

Based on published literature available, extensive reviews have been conducted from four different literature sources.

ASTM International (formerly the American Society for Testing and Materials) developed a testing standard to compare the performance of temporary ditch checks to a bare soil baseline in protecting earthen channels from stormwater-induced erosion. The proposed testing protocol was a full-scale simulation, which reproduced the conditions typically found on construction sites at the conclusion of earthwork operations and before vegetation establishment. Therefore, the tests were performed under bare soil conditions. These testing procedures were described in the ASTM D7208-06 Standard Test Method for Determination of Temporary Ditch Check Performance in Protecting Earthen Channels from Stormwater-Induced Erosion, and are discussed below.

The proposed facility is composed by twelve testing channels excavated to a trapezoidal cross-section with 0.6 m bottom width and 2H:1V side slopes, and with a recommended bed slope of 5%. The channels should be 18.3 m in length to allow sufficient distance to install temporary ditch checks in series. The apparatus for performing product evaluation include a water delivery system that will generate the required hydraulic conditions for test operation, a velocity probe to identify flow conditions during product evaluation, and a total station that will be used to detect where deposition and degradation occurs within the channel.

Before product evaluation, a 45 cm thick soil layer is placed in the constructed channels and compacted to 90 ± 3% of standard proctor density in accordance with Test Method D698. The temporary ditch check product to be evaluated is installed 12.2 m from the channel head to ensure uniform and extended flow conditions. The next operation is to install benchmarks every

1.5 m along the length of the channels to serve as a reference for the channel surveys before and after product evaluation. Prior to the product evaluation itself, detailed site conditions (including soil type information) should be documented as well.

Once the channel has been prepared and surveyed, the temporary ditch check products are installed according to the manufacturer's recommendations. The recommended target flow for product evaluation is 0.085 m^3s^{-1}, with test duration of 30 min. At the conclusion of the test, channel surface elevation should be measured at the same points used prior to testing to determine the amount of soil displaced in the testing channel. Finally, the Clopper Soil Loss Index (CSLI) and the Soil Aggradation Index (SAI) will be calculated from the topography data gathered before and after test operation using the total station equipment.

The second testing protocol reviewed is The Texas Transportation Institute (TTI), which details an official testing program to classify sediment retention devices on the basis of their sediment removal performance. The proposed testing protocol (McFalls, 2009) is based on the ASTM D6459 Standard Test Method for Determination of Rolled Erosion Control Product (RECP) Performance in Protecting Hillslopes from Rainfall-Induced Erosion. The testing facility is located at the Texas Department of Transportation- TTI Hydraulics, Sedimentation, and Erosion Control Laboratory (HSECL) on the Texas A&M University Riverside Campus.

The facility for testing sediment control devices consists of a mixing tank capable of generating sediment-laden water, a concrete parabola-shaped channel 5.5 m long, and a collection system downstream of the channel. Two turbidity meters are installed to compute the total turbidity reduction of the products being tested. One turbidity meter is installed at the outlet of the mixing tank, and the other at the downstream collection system after the water has passed through the installed sediment retention device.

The sediment removal efficiency of five different sediment retention devices was presented by McFalls et al. (2010). Water samples were taken at the inlet of the channel and at the outlet to measure Suspended Solids Concentration (SSC), so that the sediment removal efficiency could be computed. Treated wattle provided the best sediment removal efficiency and ranged from 54 to 63%. The untreated wattle's sediment removal efficiency was between 45 and 46%, the Geosynthetic dike removal efficiency was between 17 and 20%, and the silt fence removal efficiency ranged from 14 to 16%. Rock check dam was also evaluated, and its results showed a deficient sediment removal efficiency of 2%.

The third testing protocol reviwed was proposed byTheisen and Spittle (2006). They proposed an alternative test methodology to the ASTM D7208-06 standard test method for evaluating sediment retention and stormwater treatment devices on slopes and in channels. The testing equipment consisted of a mixing tank capable of creating sediment-laden water, a non-permeable slope surface to convey the sediment-laden water from the tank, the testing channel, and the collection tank located at the end of the channel.

The testing channel was prepared using the same soil type as the one used to produce the sediment-laden water. The soil placed in the testing channel was compacted to greater than 90% standard Proctor before proceeding to product installation following the manufacturer's recommendations. The flow rate was calculated based on a 10-year 6-hour storm event producing 100 mm rainfall. A theoretical contributing area of 30 m slope length by 6 m width was selected to limit runoff to sheet flow conditions. Additionally, the associated sediment load was calculated using the Modified Universal Soil Loss Equation (MUSLE) to determine a storm specific quantity of sediment. The discharge (80 L min^{-1}) was released for 30 min.

Grab samples were taken at 10-minute intervals from the mixing tank and from the runoff entering the collection tank. The cutoff time was 90 minutes. Finally, the weight and the height of the collection tank were also recorded. Five sediment retention devices were tested according to this methodology. Sediment retention, sediment concentration, and turbidity were the parameters used to compare the product efficiency. The results from the testing program carried out by Theisen and Spittle in 2004 are presented in Table 3.1.

Table 3.1. Water quality effectiveness for products tested by Theisen and Spittle, 2006.

Sediment Retention Device	Sediment Retention	Sediment Concentration (mg L^{-1})	Turbidity (NTU)
Fiber Filtration Tube	98%	930	300
Straw/Coconut Fiber Roll	76%	14,260	4500
Compost Sock	70%	18,200	5000
Straw Wattle	68%	19,100	7000
Excelsior fiber Roll	65%	20,600	7500

The results illustrate that the Fiber Filtration Tube performed better in terms of sediment retention and turbidity (NTU) as compared to the other four products when tested under the described conditions. The remaining four products presented similar efficiencies in sediment retention. In terms of turbidity reduction, the Straw/Coconut Roll and the Compost Sock had similar performance, while the Straw Wattle and the Excelsior Fiber Roll yielded higher turbidity values.

The fourth testing methodology reviewed was developed by Wolfe and Peters (2009) The testing methodologies proposed were a laboratory scale testing protocol to evaluate the efficiency of sediment retention devices in an inexpensive and efficient manner. The testing protocol proposed was based on the ASTM D5141 standard test method for bench-scale silt fence filtration efficiency and flow rate.

The testing protocol included a flume that was 1.25 m in length, 0.85 m wide and 0.3 m in depth. The flume was positioned at approximately an 8% slope. A section of the silt fence to be tested, or any other sediment retention device (SRD), was placed at the lower end of the flume. The SRD was sealed to prevent leakage at the flume edges.

A 50-liter tank with sediment-laden water was used to provide the water delivery system. The soil used as sediment for the mixture was passed through a No. 10 sieve before mixing. The sediment-laden water was mixed to a concentration of approximately 2890 mg L^{-1}. The discharge release rate was 5 L s^{-1}. The effluent was collected with a tray system placed at the downslope end of the flume. Once all water was drained through the SRD, the effluent was mixed, sampled, and compared to TSS (total suspended solids) influent concentration in order to compute removal efficiencies.

This methodology entailed some concerns. Field conditions were not simulated in this protocol, and the installation guidelines and the anchoring pattern didn’t follow the manufacturer´s recommendations. A drawback of this operating methodology for SRDs was the edge effect that occurs when testing in a flume. This effect took place around the contact surface of the SRD and the flume walls, but was minimized by sealing the surfaces using a foam sealant along the base edge and the sides to prevent from water leakage.

In their report, they include a testing protocol conducted by Civil & Environmental Consultants, Inc. (CEC) for a new SRD. The product evaluated was TYCELL™ manufactured by Fiberweb™. This product was a rolled SRD filled with different materials. The tests were designed to determine the hydraulic capacity of the product under slurry and clean water conditions, along with its sediment retention capacity. A 1.2 m wide, 4.9 m long, and 0.45 m deep flume was designed for testing operation. The flume was placed in a 1% slope. The edges of the devices were sealed with a foam sealant to minimize the edge effect. Concentrated flow and interrill simulations were performed to determine the sediment removal efficiency of TYCELL^{TM}.

For the concentrated flow simulations, the SRD was filled with rock from 3 to 8 inches in diameter. A sediment-laden water mix was prepared with Sil-Co-Sil 106 manufactured by US Silica Company. Sil-Co-Sil 106 was chosen due to its ability to maintain solids in suspension from the mixing tank to the flume reaching the desire suspended solid concentration

The sediment-laden water was prepared with a concentration of between 1000 and 3000 mg L^{-1}. The discharge rate of 204 L min^{-1} was used to avoid overtopping and the test duration was 30 minutes. Grab samples were taken every 5 min in the influent and in the effluent to analyze for both TSS (total suspended solids) and SCC (suspended soils concentration).

For the interrill simulations, the same flume was used. The sediment-laden water was mixed in a 470 liter tank, and the concentration of the mix was between 1,000 and 3,000 mg L^{-1}. The test was conducted for 30 minutes with a discharge rate of approximately 16 liters per minute. Influent and effluent samples were taken every 5 minutes. The flow rate was 16 liters per minute and the SRD was filled with shredded wood mulch. This procedure was also performed for Geotex 2130 (a silt fence manufactured by Propex) and a straw wattle 23 cm in diameter.

The paper did not provide any quantitative testing results, but according to the authors the experiments showed a significant improvement in sediment removal and water quality using TYCELL^{TM} as compared with the silt fence and the straw wattle. This evaluation has been reviewed only for testing procedure purposes and not the specific findings by the authors in terms of product performance. This is due to the large concentration range of the sediment-laden water used in the testing protocol and the absence of reliable and detailed results.

3.4 Erosion Control Blanket Product Field Evaluation

The Hydraulics and Erosion Control Laboratory at Texas A&M University was designed in collaboration with the Texas Transportation Institute to develop methodologies for evaluating the performance of erosion and sediment erosion control products commonly used in construction activities (Godfrey and Curry, 1995). Erosion control blankets were evaluated in a two-year study to compare the effectiveness of erosion control blankets in enhancing the growth of warm season perennial vegetation while preventing soil erosion in 3:1 and 2:1 slope conditions. This study was intended to simulate the typical side slopes of highways with plots 6 m in width and 300 m in length. Twelve products were randomly installed in the plots and replicated for two soil types (clay and sand) for each slope condition, with a control plot for each slope and soil type. Before installation of erosion control blankets, the plots were graded and raked in order to prepare the soil bed for the seeding. The plots were fertilized and hydroseeded with a native and grass mixture that varied with the soil type. The products were evaluated for sediment retention and vegetative density with respect to soil type and slope conditions.

Each treatment was evaluated under a series of simulated rainfall events. The rainfall events corresponded to a 1 year return period (30.23 mm h^{-1}), a 2 year return period (145.54 mm h^{-1}), and a 5 year return period (183.64 mm h^{-1}). The duration of the simulated rainfall events was 10 minutes for all cases. Simulated rainfall events were performed 24 hours apart from any natural rainfall event, and under no wind conditions to minimize the effects of wind in the rainfall distribution over the evaluation plots. Runoff was collected after every simulated rainfall event to determine the sediment yield for each treatment.

The results of this study indicated that the sediment retention and vegetative cover establishment was significantly better for erosion control blankets in comparison with the control plots for highly erodible soils (sandy soils), regardless of the slope condition. For cohesive soils (clay soils) it was found that erosion control blankets significantly improved sediment retention (to at least 75%), relative to the control plot. A minimum of 5% more vegetation establishment was achieved in the erosion plots with erosion control blankets installed as compared to the control plots.

Benik et al. (2003a; 2003b) studied erosion control products under Minnesota highway side slope conditions. Five erosion control products were evaluated on a slope of approximately 2.8:1 with a length of 9.75 m. The width of the plots varied depending on the width of the rolled product evaluated. The products evaluated included straw mulch, three different erosion control blankets, and a control plot. The erosion plots were fertilized, seeded with native grasses, and raked prior to product installation.

The runoff from the erosion plots was measured with a tipping bucket installed at the base of each plot, and approximately 15% of the runoff was diverted to a collection tank so that grab samples could be taken. Rain gauges were also placed around the periphery of each pair of adjacent plots to estimate the spatial variation of the simulated rainfall events. Biomass was collected by harvesting grasses with a gas-powered trimmer and drying the samples at 75^{o}C for 24 hours for each of two consecutive growing seasons Benik et al. (2003a). All treatments evaluated significantly reduced the erosion as compared to the control plot. The straw mulch treatment was also found significantly less efficient in terms of sediment retention when compared to the other treatments during the spring, but not during the fall.

A more detailed review of literature for evaluation and performance of erosion control blankets under laboratory and field scale conditions can be found at Monical's Master Thesis (2011).

CHAPTER 4

METHODOLOGY

4.1 Field Site

The erosion and sediment control studies for ditch check products and erosion control blankets were conducted at the ESCRTC (Erosion and Sediment Control Research and Training Center) located in the Agricultural and Biological Engineering South Farm, which belongs to the University of Illinois at Urbana-Champaign. The total area of the demonstration and research site was 1.6 ha. The site contained an elbow shaped berm, a detention pond, and three channels. An aerial view of the ESCRTC testing facility is presented in Figure 4.1.

The elbow shaped berm measured approximately 91.4 m in length and 3.7 to 4.1 m in height. The southwestern face of the berm had a slope that ranged from 3.1:1 to 3.4:1, with an average value of approximately 3.25:1; the northeastern face had a slope that ranged from 2.5:1 to 2.6:1, with an average slope value of approximately 2.55:1.

The detention pond had an approximate surface area of 1271 m^2 and a maximum storage volume of 1826 m^3. The detention pond provides the water supply for the testing and evaluation performed at the site. The three channels were constructed with target lengths of 61 m and bed slopes of 2%, 3%, and 4%. The 1% and 4% slopes had straight configurations, while the 3% slope channel had an elbow configuration with a bend approximately near the center (Monical, 2011). Only the channel with 4% slope was used in this study

Figure 4.1. Aerial view of the ESCRTC research and demonstration site (Google maps).

4.2 Ditch Check Evaluation

Three different ditch check products were evaluated in this study: Sediment Logs, GeoRidge plastic berms, and Triangular Silt Dikes. All products were evaluated according to the testing protocol described in section 4.2.5.

4.2.1 Ditch Check Products

4.2.1.1 Sediment Log

The Curlex Sediment Logs were manufactured by American Excelsior and contained curled excelsior wood fiber in rolls of various diameters. The fibers were curled with soft interlocking barbs, of which 80% were six inches in length or longer. Sediment Logs were designed to provide temporary, biodegradable channel interruption by slowing water velocity to reduce shear stress over the channel, thereby minimizing soil degradation in the channel and enhancing vegetation establishment (www.americanexcelsior.com).

The Sediment Logs evaluated were Type II (30 cm diameter) and designed to be used in mild to medium concentrated flow areas. The product was installed in accordance to manufacturer's installation guidelines, staking pattern guide, IDOT recommendations, and CAD details. The installation guidelines are available at www.americanexcelsior.com.

Figure 4.2. Sediment Logs installed at field study site.

4.2.1.2 Plastic Dam (GeoRidge®)

The GeoRidge check dams were permeable plastic berms manufactured by Nilex Inc. and designed for erosion and sediment control. The GeoRidge plastic dams were made of a durable UV stabilized High Density Polyethylene (HDPE) (www.nilex.com).

GeoRidge dams were intended to reduce water velocity, spread water over a wider area, trap sediment, and aid in vegetation establishment. According to the manufacturer's specifications, the product should be removed once vegetation is established. This product could then be reused after removal in future projects (www.nilex.com). The product was installed according to the manufacturer's guidelines, which are available at www.nilex.com.

Figure 4.3. GeoRidge® installed at field site.

4.2.1.3 Triangular Silt Dike^{TM}

The Triangular Silt Dikes were manufactured by the Triangular Silt Dike company, Inc. and contained triangular urethane foam wrapped in geotextile fabric. The product was available in multiple heights, but the 25 cm model was used in this study. The product was designed with protective aprons on both sides of the barrier to prevent erosion and product failure (www.tri-siltdike.com). The product was installed following the manufacturer's installation guidelines available at www.tri-siltdike.com.

Figure 4.4. Triangular Silt Dike^{TM} 25 cm barrier installed at field study site.

4.2.2 Field Site Soil and Channel Details

The site exhibited a relatively equal mix of silt loam and silty clay loam soils. Specific soil series included Brenton (38%), Drummer (47%), and Flanagan (15%), as indicated by the Soil Survey Geographic (SSURGO) Database (Soil Survey Staff, 2011). Both Brenton and Flanagan soils are very deep and somewhat poorly drained silt loams, with depths to carbonate layers of greater than 102 cm and from 114 to 165 cm, respectively. The surface layer of both soils typically have a clay portion of 20% to 27%; additionally, Brenton surface layers exhibit an organic matter content of 3% to 5%, while Flanagan ranges from 4 to 5%. Drummer soils are very deep and poorly drained silty clay loams, with depths to carbonate layers of greater than 102 cm. The Drummer surface layer typically has a clay portion of 27% to 35%, with organic matter ranging from 4% to 7%. The average saturated hydraulic conductivity at the surface for all three soils ranges from 1.5 to 5 cm h^{-1} (Endres, 2003).

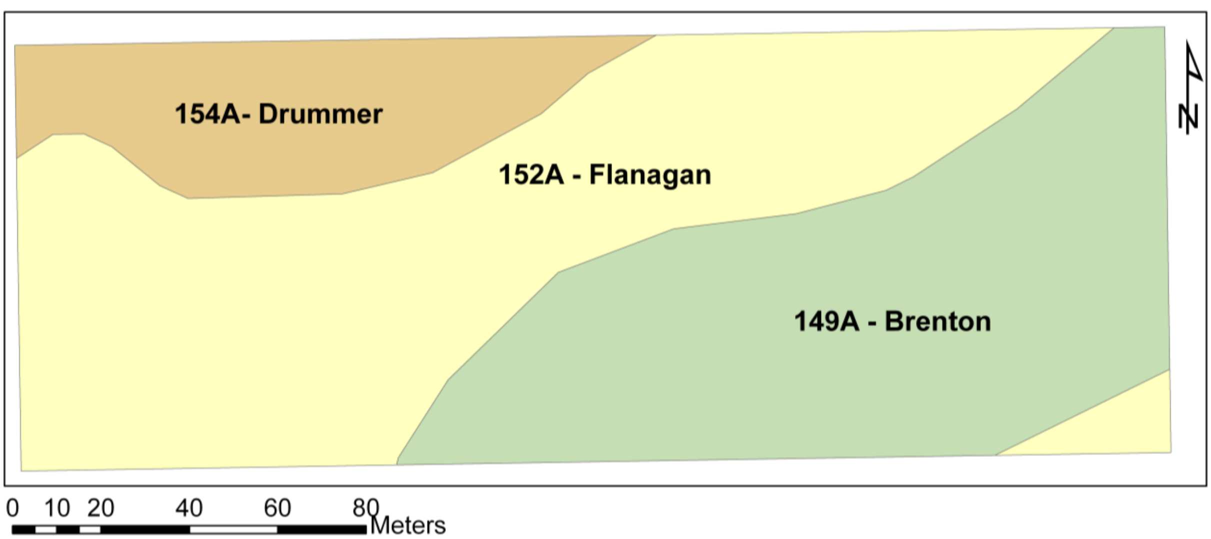


Figure 4.5. Site soil distribution prior to site development, August 2009 (Monical, 2011).

The testing channel had a 4% bed slope, with a parabolic shape that simulated the typical channel profile found in construction sites and roadside ditches. The channel had a top width of 3 m at the upstream end and 7.9 m at the downstream end of the channel. The channel side slope was 2(H):1(V) throughout the channel profile. The total length of the channel was 61 m. The ESCRTC facility also had two additional curved channels with bed slopes of 2% and 3% for training and demonstration purposes; however, these channels could also be utilized for product testing if required (Monical, 2011). The 4% bed slope channel utilized for testing is shown in Figure 4.6.

Figure 4.6. Ditch check testing channel with 4% bed slope.

The testing channel was divided into two zones: the discharge zone and the testing zone. The discharge zone received the water from the pumping station. The discharge zone was stabilized with a turf reinforcement mat (TRM) and vegetation to minimize erosion in the discharge zone and the sediment concentration of the flow before reaching the testing zone. Figure 4.7 shows the channel stabilization with a TRM prior to and following vegetation establishment. The products to be evaluated were installed in the testing zone, which measured 50 m in length in order to meet the spacing requirements of the products in series.

(a) **(b)**

Figure 4.7. (a) Discharge zone stabilization with TRM prior to vegetation establishment and (b) permanent channel protection after vegetation establishment.

To measure the channel flow rate, a Plexiglas 90° V-notch weir was installed across the width of the channel between the discharge and testing zone. The V-notch weir was installed on a 1 m depth trench with an initial layer of cement approximately 30 cm thick, and then covered by compacted soil.

4.2.3 Water Supply and Delivery System

The detention pond served as the water supply for the ditch check product evaluation and the rain simulator used in the evaluation of erosion control blankets. The capacity of the pond was adequate for the water requirements during testing. The maximum flow requirements for the ditch check product evaluation was 10 L s^{-1} during a total test time of 30 min. The water was conveyed to the channel by a 6.0 kW trash pump with a maximum head of 29 m at 25 L s^{-1}.

The pump was placed in the center of the eastern side of the detention pond. The pump was supplied by a 7.62 cm inner diameter suction hose. The strainer at the end of the suction hose was held by a metal post 0.6 m above the pond's bed to prevent soil from entering the pump, while also keeping the suction hose far enough below the water surface so that air was not suctioned either. A 7.62 cm flexible discharge hose conveyed the water from the pump to the discharge zone at the head of the channel.

4.2.4 Channel Scanning Equipment

A laser scanning distance meter, Leica 3D Disto, was used to record precise elevation profiles of the channel surface. Sequential channel profile scans were performed before and after product testing to generate successive surface profiles and provide an accurate estimate of the sediment deposition. To estimate the sediment deposition on the upstream side of the product being tested, a 2 m section along the entire width of the wetted surface was scanned. The laser scanning distance meter was used to take elevation measurements over a 10 cm by 10 cm grid covering the scanned area. The elevation measurements were interpolated using kriging to produce a 3-dimensional profile of the scanned area. The successive scans performed were used to compute the total volume of sediment deposited in that area. A picture of the laser scanning distance meter during scanning operation is displayed in Figure 4.8.

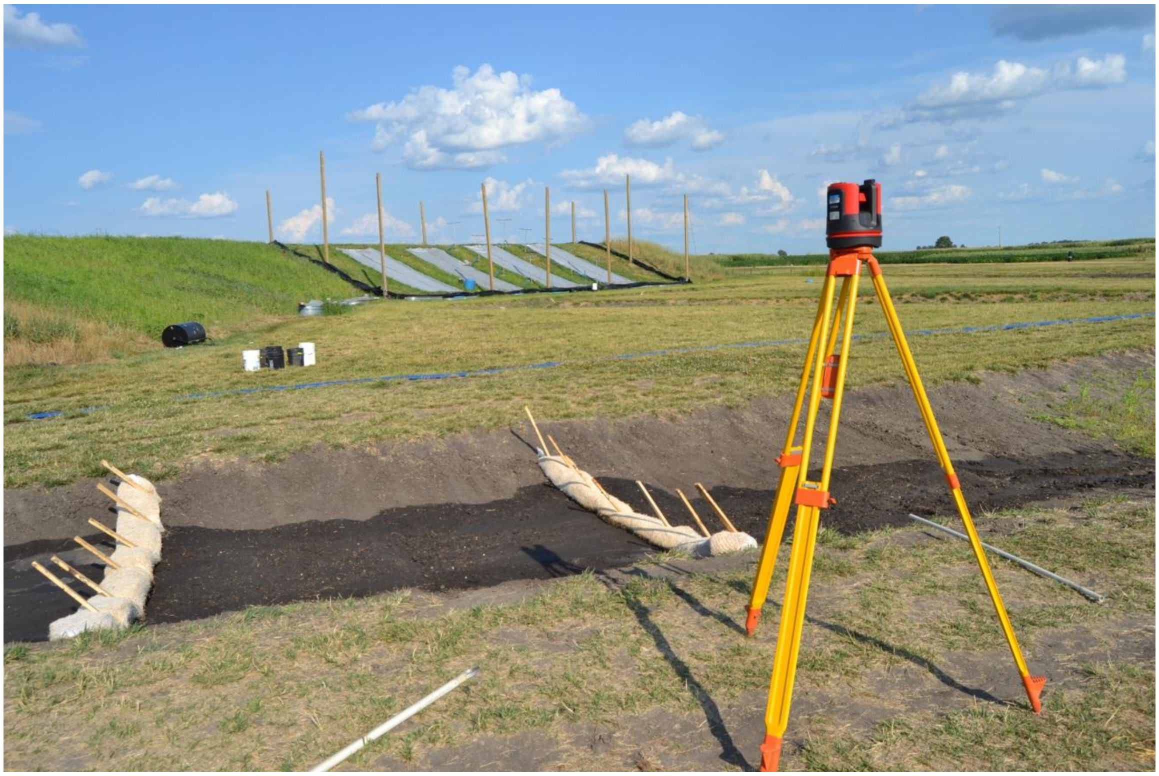


Figure 4.8. Laser scanning distance meter during ditch bed scanning operation.

4.2.5 Testing Protocol for Sediment Control (Ditch Check) Products

This section outlines a full scale testing and evaluation protocol for ditch check products at the ESCRTC. The proposed testing protocol is based on ASTM D 7208-06 (ASTM, 2007c), and was used to test the performance of ditch check products and perform training and demonstration activities. The protocol will also help to update the list of accepted ditch check products in protecting earthen channels from stormwater-induced erosion, as well as evaluate new products. The testing protocol reflects the conditions typically found on construction sites around Illinois.

4.2.5.1 Apparatus

The proposed design for the testing and evaluation protocol required the following components: water source and delivery system, testing channel, soil stockpile, earthmoving and compacting equipment, total station, monitoring system, and miscellaneous other equipment.

a) Water supply and delivery system

The retention pond, located at ESCRTC facility, served as the water supply source. The water delivery system included the necessary pumps and piping in order to reach the required hydraulic conditions to operate testing, as described in section 4.2.3. The water was discharged onto a stabilized surface to avoid soil erosion before the discharge is measured and the water reaches the head of the testing channel. The recommended discharge measurement equipment is a 90^{o} V-notch weir (see Figure 4.9), which is most accurate when measuring discharges of less than 0.315 m^3s^{-1} (Allen G. Smajstrla, 1981). Other optional equipment, such as flow meters, may also be used to measure flow discharge.

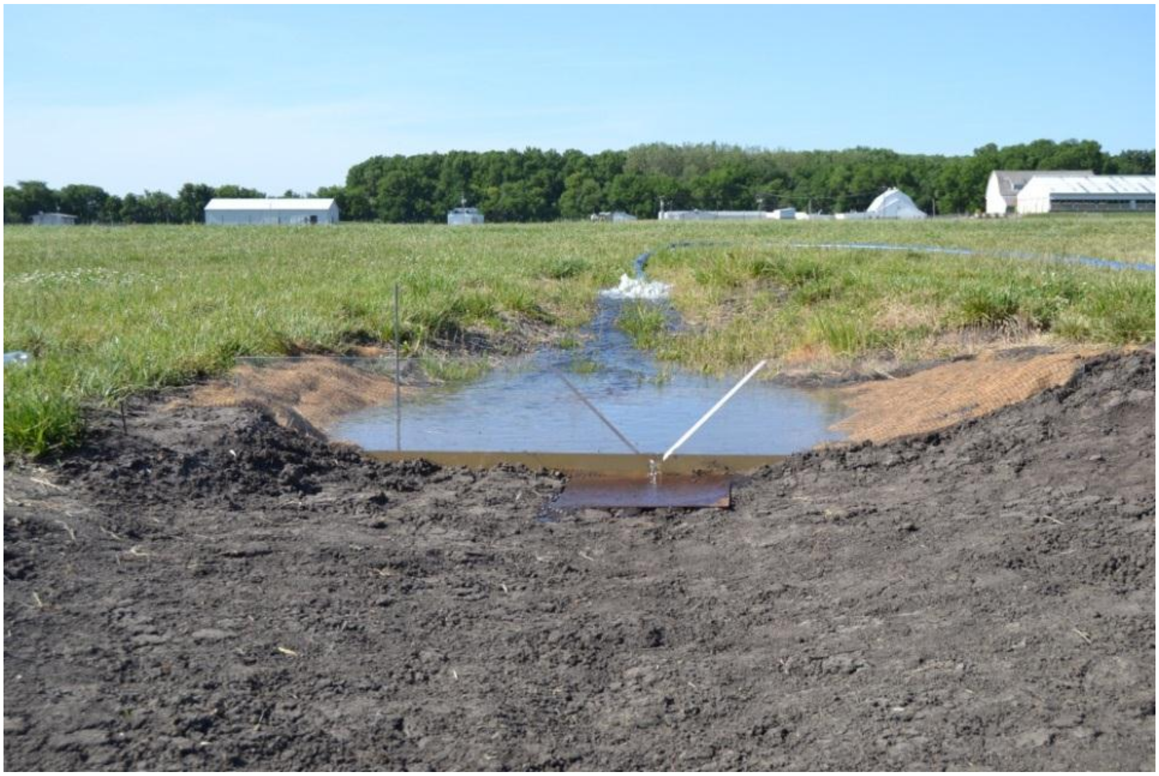


Figure 4.9. 90° V-notch weir for flow rate measurement, and discharge zone stabilized with a turf reinforcement mat (TRM).

b) Soil stockpile

A stockpile of soil is required of adequate quantity to replace eroded soil in the testing channel.

c) Earthmoving and compacting equipment

This equipment included a front-end loader to move soil from the stockpile into the testing channel when needed, a self-propelled tiller to obliterate any rills, rakes to repair and smooth the surface, and a soil compactor.

d) Scanning equipment

A laser distance meter was used to measure relative elevations of points with an accuracy of ±2 mm, along with a data logger and related software for calculations (see section 4.2.4 for further details).

f) Monitoring system

A 90^{o} V-notch weir was used to measure the flow rate into the system, which was installed at the head of the channel. The other equipment in the monitoring system will consist of a turbidity meter, a penetrometer, and a soil moisture meter. Periodic calibration of the equipment was performed as required.

g) Miscellaneous

Other miscellaneous equipment includes a weather station (capable of measuring wind speed, temperature and precipitation), and audiovisual equipment such as a camera and video recorder.

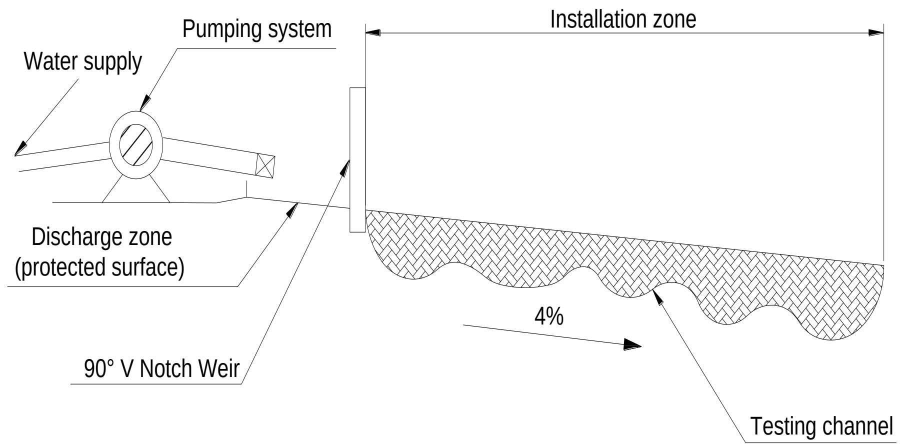


Figure 4.10. Diagram of evaluation procedure (not to scale).

4.2.5.2 Test Preparation

a) Channel preparation

Channel preparation began by loosening the channel surface to a depth of approximately 10 cm using a self-propelled tiller. If testing was previously performed eroded soil was discarded and replaced with soil of the same kind from the stockpile. Any foreign material (vegetation, roots, or stones) that could have interfered in the products evaluation was removed from the testing channel. Finally channel surface was smoothened with a hand rake and compacted using a 400 kg lawn roller.

Figure 4.11. Soil compaction operation using the lawn roller during channel preparation.

b) Soil moisture measurement

The soil moisture content was measured at 10 to 15 random points along the channel length. If the soil moisture content was lower than 70% of saturation level, the channel was wetted using the rainfall simulator system until a minimum of 70% is achieved throughout the channel profile. The channel surface was smoothened again using the hand rake and compactor if necessary. Testing at other soil moisture conditions can also be performed if required.

c) Ditch Checks installation

The ditch check was installed after channel preparation was completed, following the manufacturer´s installation guidelines. Two ditch checks were installed in series.

For evaluating the performance of ditch checks in series, the spacing pattern followed the manufacturer's recommendations. If there were no recommendations available, spacing between ditch checks was computed as:

$$D = \left(\frac{H}{S}\right) \times 100 \tag{1}$$

where,

D = spacing distance (m)

H = distance between channel bed and top of installed temporary ditch check (m)

S = Slope of channel bed (%)

This distance is calculated to position the bottom of the upstream ditch check and the top of the downstream ditch check at the same elevation.

d) Elevation measurement

Elevation measurements were taken using the scanning equipment. The measurement pattern consisted of a rectangular grid with 10 cm by 10 cm spacing. The scanned area was on the upstream side of the ditch check. The scan was performed along a 2 m section upstream from the ditch check and across the entire wetted width of the channel.

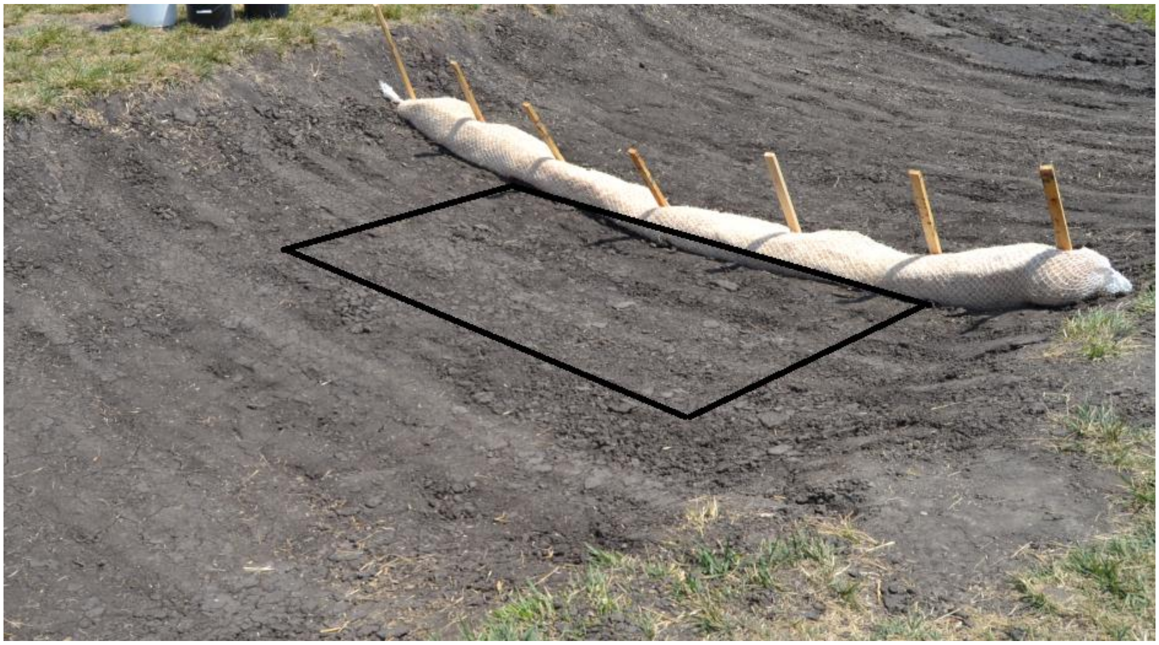


Figure 4.12. Elevation measurement pattern (not to scale).

e) Visual documentation

Photographs were taken of the channel conditions and the ditch check installation before, during, and after performance of the test. It was also recommended to record video of the test operation, but this was not required.

f) Discharge calibration

The discharge calibration was performed in one of the demonstration channels or in the testing channel prior to channel preparation. Once the desired steady-state flow rate was achieved, the ditch check evaluation commenced.

4.2.5.3 Test Operation and Data Collection

a) Channel pre-test scan

Channel scanning was performed after channel preparation and prior to the test. Once scanning was completed, the product evaluation was performed under a particular flow condition.

b) Product evaluation and flow conditions

The product evaluations were run for 30 min (or until product failure) for three different flow rates of 5, 7.5, and 10 L s^{-1}. 350 ml grab samples were taken at 5 minute intervals from the upstream and downstream sides of every ditch check installed. At the same time and locations, turbidity measurements were taken with the turbidity meter. The cutoff time for sample collection was 30 minutes.

Once the test has completed and any remaining water has drained out of the channel, then scanning can be performed. This second scan will allow computation of the total sediment deposition in front of the ditch check after the first test.

Figure 4.13. Grab sample gathering during test operation.

The second replication was performed after the post-test scanning was completed. This second replication was done under the same flow conditions and without product removal and channel preparation. This allowed computation of sediment accumulation after successive events and different soil moisture conditions. As in the first replication, post-test scanning was performed after any remaining water had drained out of the channel. Finally, a third replication was performed following the same methodology as for the second replication.

This procedure results in a total of four channel scans for each testing sequence: an initial scan after channel preparation and a post-test scan after every replication. This procedure was followed for each of the three flow conditions previously described.

d) Data analysis

Total sediment concentration for each sample was measured based on the procedures in ASTM D3977-97 Standard Test Methods for Determining Sediment Concentration in Water Samples (ASTM, 2007b). The grab samples were taken to the laboratory for total sediment concentration determination and placed in a drying oven at $98^{o}C$ for 24 hours to evaporate most of the water. In order to completely dry the sediment the samples were left in the oven at $105^{o}C$ for an additional 24 hours.

The turbidity in Nephelometric Turbidity Units (NTU) was measured for all grab samples, and the relative reduction in NTU was computed between the upstream and downstream sides of each ditch check under evaluation. the total volume of sediment retained by each ditch check was computed using the scanned topographic data gathered before and after test operation with the laser distance meter equipment. Using the commercial software SURFER the total sediment volume was estimated.

e) Synthesis of evaluation

All data and measurements (sediment volumes, NTU, SSC) from testing a specific ditch check was compared to the results from other ditch checks tested under similar replicable conditions. The results were shared and discussed in detail with members of the relevant IDOT Technical Review Panel. Based on the test results and the discussions, performance of any ditch check could be recommended.

4.3 Erosion Control Blanket Evaluation

Three different erosion control blankets were evaluated in this study: Curlex® I, DS75, and SC150. All products were evaluated according to the testing protocol described in section 4.3.2.

4.3.1 Erosion Control Blanket Products

4.3.1.1 Curlex® I

The Curlex® I erosion control blankets were manufactured by American Excelsior Company. They consisted of barbed, interlocking, curled wood excelsior, with 80% of fibers six inches or longer. They were designed to be of consistent thickness, with fibers evenly distributed throughout the entire area of the blanket. The top of the blankets were covered with single photodegradable single netting, and all materials were free of seeds or chemical additives. The manufacturer recommended the use Curlex® I in 2H:1V and flatter slopes for shear stresses of 84 Pa (www.americanexcelsior.com). The Curlex® I blankets were installed for evaluation following the manufacturer's installation guidelines available at www.americanexcelsior.com

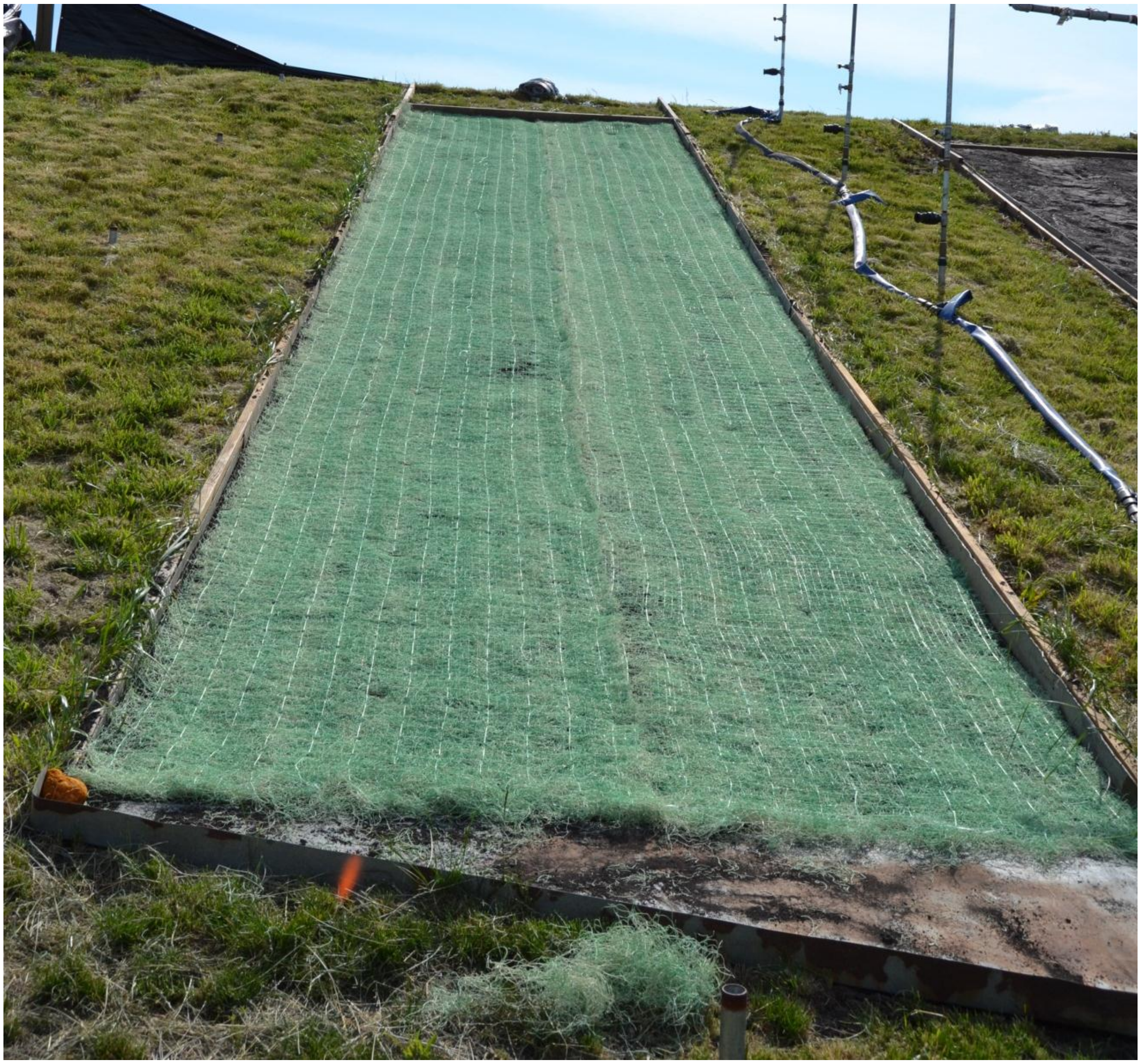


Figure 4.14. Curlex®I installed at field site.

4.3.1.2 DS75

The DS75 erosion control blankets were ultra-short term single net blankets consisting of 100% agricultural straw and manufactured by North American Green. They were designed to provide a functional longevity of up to 45 days, which could vary depending upon climatic conditions, soil, geographical location, and elevation. The blankets were of consistent thickness with the straw evenly distributed over the entire area of the mat, and covered on the top side by polypropylene netting with photodegradable accelerators to provide breakdown of the netting(www.nagreen.com). The DS75 blankets were installed according to manufacturer's installation recommendations available at www.nagreen.com.

Figure 4.15. DS75 installed at field site.

4.3.1.3 SC150

The SC150 erosion control blankets were extended term double net products manufactured by North American Green. They consisted of 70% agricultural straw and 30% coconut, with a functional longevity up to 24 months. The blanket was designed to be of consistent thickness with the straw and coconut fiber evenly distributed over the entire area of the mat. The blanket was covered on the top side with heavy weight photodegradable polypropylene netting with ultraviolet additives to delay breakdown, and on the bottom side with light weight photodegradable polypropylene netting (www.nagreen.com). The SC75 blankets were installed according to manufacturer's installation recommendations available at www.nagreen.com.

Figure 4.16. Erosion control blanket SC150 installed at field site.

4.3.2 Erosion Plots

The erosion plots were designed based on ASTM D6459-07, but modified due to size constraints of the berm. The plots were 10.7 m in length (instead of 12.4 m as described in ASTM D6459-07) and 2.4 m in width, with an approximate slope of 3H:1V (Monical, 2011). An overview of the four erosion control plots is shown in Figure 4.16.

Figure 4.17. Erosion control plots at the ESCRTC testing site.

The runoff from the erosion control plots was conveyed into the collection tanks by a runoff tray installed at the bottom of the erosion plots (Monical, 2011), see Figure 4.18. During testing, the runoff tray was covered with a metal plate in order to avoid collecting water that did not result from erosion control plot runoff. The portable metal plate can be seen in Figure 4.19.

Figure 4.18. Modified runoff tray at base of plot. (Monical, 2011).

Figure 4.19. Runoff tray covered with metal plate for erosion control blanket testing.

4.3.3 Water Delivery System

As described in section 4.2.3, the detention pond served as the water supply for erosion control blanket evaluation. The maximum flow requirement for evaluation was 7.31 L s^{-1}, and the total time of pump operation varied depending on the required length of pre-evaluation plot saturation. The water was conveyed to the rainfall simulator by a 4.1 kW pressure pump, with a maximum head of 57 m and discharge of 7.31 L s^{-1}.

The pump was positioned near the center of the pond's eastern edge, approximately 80 m from the southern end of the berm. The pump was supplied by a 5.1 cm suction hose connected to a horizontal, floating PVC pipe 6.1 m in length and 5.1 cm in diameter. This connected via a 90° PVC elbow to a capped vertical PVC section 30 cm in length 7.6 cm in diameter, which served as the intake filter. A grid of 1 cm holes was drilled around the lower portion of the vertical piece, and then wrapped in aluminum wire screen to prevent algae and sediment particles from entering the filter. The filter was suspended in the water by a floating square of connected PVC pipe 15.2 cm in diameter, with a gap on one side and the exposed ends capped. A metal crosspiece was secured across the top of the square, and the end of the filter was positioned through the gap and hung from the crosspiece. A 5.1 cm diameter collapsible discharge hose connected the pump to the sprinkler tree configuration (Monical, 2011).

4.3.4 Outdoor Field Scale Rainfall Simulator

The outdoor rainfall simulator described by Monical (2011) included a set of nine sprinkler trees placed around the perimeter of the erosion plot, as shown in Figure 4.20. Each tree was placed a distance of 1.2 m from the plot border.

The ASTM standard recommended a nozzle height of 4.3 m, but for ease of movement and to overcome wind effects due to small droplet size, the initial configuration was shortened to a 1.9 m height. The trees were secured in the ground through a base support of 31.8 mm diameter galvanized steel pipe 91.4 cm in length that was inserted into the ground to a depth of 81.3 cm. A 31.8 mm flexible coupler just below the check valve on each tree allowed the tree to fit snugly over the base support. An illustration of the basic tree and base support is depicted in Figure 4.20 (Monical, 2011).

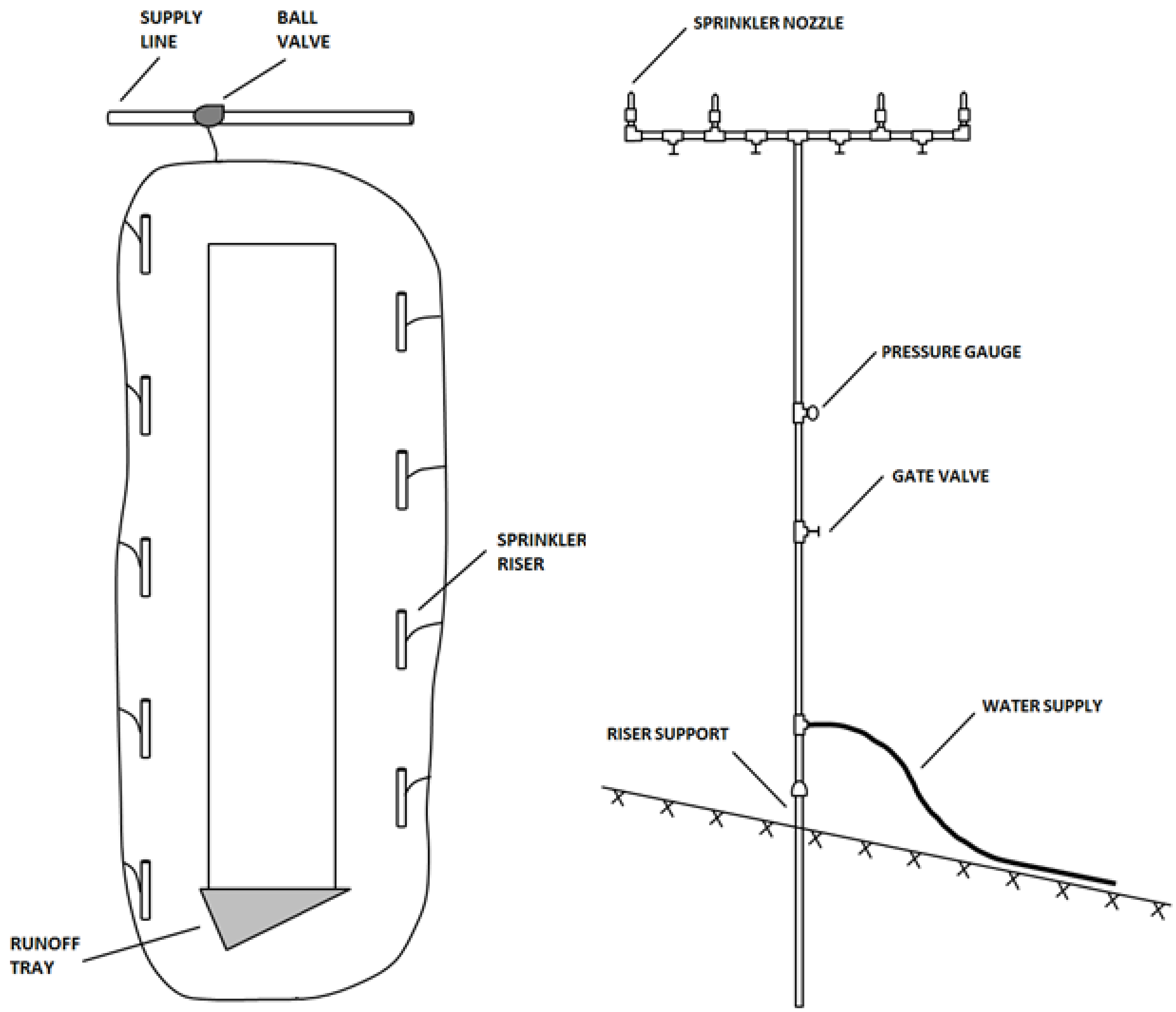


Figure 4.20. Sprinkler tree configuration and structure (ASTM, 2007a). (Monical, 2011).

The TTI11006 Turbo TeeJet induction flat spray tip nozzle was selected because it had the highest capacity of any of the largest droplet size TeeJet nozzles. This nozzle had a discharge of 2.0 L min^{-1} at 207 kPa, which was adequate for the required intensity of 100 mm h^{-1} (Monical, 2011).

4.3.5 Testing Protocol for Erosion Control Blanket Products

An evaluation protocol based on ASTM D6459-07 was developed for testing various erosion control products at the site. The four plots would be used to test three replications of a single product and one control plot of bare soil.

4.3.5.1 Test Preparation

All plots were tilled to a depth of 10 cm, raked, and compacted with a tamper. The erosion control blankets (ECBs) to be tested were installed following the manufacturer installation guidelines in three of the erosion control plots.

Figure 4.21. Plot tilling operation prior to erosion control blanket installation.

Once the erosion control blankets were installed, at least ten soil moisture content measurements were taken randomly throughout the plot to check for soil saturation. If this condition was not satisfied, the rainfall simulator was run and additional soil moisture measurements were taken until complete soil saturation was reached. The soil and the installed product were saturated to ensure that all products being tested had the same saturation conditions; as some products were able to absorb water when they were not saturated much more than others, this can significantly affect the runoff rate.

Prior to testing, a set of nine rain gauges were placed on the plot every 1.5 m from the bottom to the top, in an alternating sequence of one centered gauge and two gauges positioned 30 cm from the plot border. The rain gauges are installed to check if the target intensity and the rainfall distribution was achieved during test operation.

Figure 4.22. Erosion control blanket saturation and rainfall simulator calibration prior to product evaluation.

4.3.5.2 Test Operation and Data Collection

During testing, a wind screen was raised to provide more consistent conditions between evaluations, and the rainfall simulator system is moved to the appropriate plot. The test operated at pressures corresponding to the target intensity of 100 mm h^{-1} for 30 minutes sequentially on each plot. Following completion of each test, the average rainfall depth was determined from the 9 measurements to verify correct calibration.

Figure 4.23. Wind screen being raised before testing performance.

Visual observations were documented and digital photographs were taken for each test. It was also recommended, but not required, to record video of the entire process. The time at start of rainfall, start of runoff, end of rainfall, and end of runoff was also recorded.

A minimum wait of 30 minutes (or at least 15 minutes after runoff has stopped) was required between plot saturation and product evaluation to ensure optimal and replicable test conditions.

The runoff was collected from the plot using a series of 19 L plastic buckets, as shown in Figure 4.23. The time at which each bucket was filled was recorded and the bucket was weighed using a digital hanging scale (see Figure 4.25). The mass of the dry, empty bucket was subtracted to yield the net runoff mass and later construct an appropriate runoff hydrograph. Simultaneously, grab samples were taken every three minutes during test operation. The grab samples were used to compute the total sediment concentration of the runoff as well as to calculate the NTUs of the water samples.

Figure 4.24. Runoff collection.

Figure 4.25. Mass of runoff collected being measured.

4.3.5.3 Data Analysis

Total sediment concentration was measured for each sample based on the procedures in ASTM D3977-97 Standard Test Methods for Determining Sediment Concentration in Water Samples (ASTM. 2007b). The samples were first placed in a drying oven set at 94°C until all visible moisture was removed. The temperature was then raised to 105°C, and the samples were dried for an additional 24 hours. The mass of each dried sample and jar was measured, and after thoroughly cleaning and drying the jars, their empty masses were recorded as well. The concentration in ppm is calculated by dividing the net sediment mass by the net sample mass, and then converted to mg L^{-1} by Equation 2:

$$C_2 = \frac{C_1}{1 - C_1(6.22 \times 10^{-7})} \tag{2}$$

where C_2 is the concentration in mg L^{-1}, C_1 is the concentration in ppm, and the bulk density of sediment is assumed to be 2.65 g cm^{-3} (ASTM, 2007b).

The total sediment yield for each test was calculated by multiplying the net mass of runoff collected in each bucket by the sediment concentration in ppm for the grab samples taken for the corresponding bucket. Finally, the sum of the net sediment mass from all samples provides the total sediment yield. The turbidity in NTUs was also measured for every grab sample taken.

To construct the runoff hydrograph, the volume of each sample was first calculated from the net mass of water from the sample and the net mass of sediment from the sample:

$$V = m_w + \frac{m_s}{2.65} \tag{3}$$

where V is the sample volume (mL), m_w is the net water mass (g), m_s is the net sediment mass (g), the density of water was assumed to be 1.00 g cm^{-3}, and the bulk density of sediment wasassumed to be 2.65 g cm^{-3}. The runoff rate during each sample collection was calculated by dividing the sample volume by the elapsed collection time. The hydrograph was constructed by plotting the runoff rates against the times corresponding to the midpoint of the sample collection. The sediment concentration curve for each test was similarly constructed by plotting the concentration for each sample against the midpoint of the sample collection time as well.

4.3.5.4 Data Analysis

All data and measurements (runoff, NTU, SSC) from an ECB test were compared among and with the bare control test them under similar replicable test conditions. The results were shared and discussed in detail deliberation with members of the relevant IDOT Technical Review Panel. Based on the test results and the discussions, performance of any ECB will be recommended.

4.4 Statistical Analysis

Due to the small number of replications and the inherent variance of the different evaluations, the most suitable statistical test with which to compare different treatments was Welch's t-test (Welch 1947). This statistical test was performed on paired samples of data to determine whether two products resulted in significantly different performance. Wright (2010) utilized Welch's t-test for a similar experimental setup. The test was performed with a significance level of $\alpha = 0.10$ for comparing both ditch check and erosion control products. To account for replications of each flow rate being performed sequentially in a series, rather than each separately with channel repreparation, a Friedman test was also performed to evaluate performance based on individual sequence position and flow rate pairings (Hollander et al. 1973).

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Ditch Check Product Evaluation

Soil samples were taken from the 4% slope channel to determine the soil texture. Soil texture was an important variable to take into account, because only results under the same soil type test condition could be compared. Future testing in other facilities or at the ESCRTC must use the same soil type in order to accurately compare results.

The particle size analysis was done following the hydrometer method described by Gee and Baude (1986). This method was a modification of the Day (1965) and ASTM (1985d) methods. The analysis results indicated that the testing channel was composed of silt-loam soil as defined by USDA soil texture classification, with 13.0% sand, 61.7% silt and 25.3% clay.

5.1.1 Results and Discussion for Ditch Check Evaluation

The ditch check product evaluation was performed using three different flow rates: a high flow of 10 L s^{-1}, a medium flow of 7.5 L s^{-1}, and a low flow of 5 L s^{-1}. The products were tested under different flow conditions to evaluate how each might differently affect the ditch check product performance. Higher total sediment concentration (TSC) was expected for higher flows, which was observed for two of the products tested: the Triangular Silt Dike and Sediment Log. The trend reversed for GeoRidge, however, with higher TSC (and hence higher channel soil loss) found for lower flows.

Each product evaluation for a particular flow condition was replicated three times. The TSC values calculated from the five-minute grab samples appeared to show a trend of declining concentration with each performed test. The sediment concentration of grab samples seemed to consistently stabilize for all products after the first 15 minutes of each test. The average TSC values for all three products under all three different flow conditions are shown in Figure 5.1 to 5.12. The TSC values for all tests are presented in Appendix A.

The average TSC values computed from grab samples for the Triangular Silt Dike under the high flow condition are displayed in Figure 5.1. The results showed a declining trend in TSC during the first 10 minutes of the evaluation, after which the TSC stabilized until the test was completed. Samples were taken at the upstream and downstream sides of each of the two ditch checks installed in series. The TSC value after five minutes is not shown for the downstream side of the downstream ditch check, however, because the flow at this location did not reach steady state until approximately ten minutes after the test began. This behavior was only observed for the Triangular Silt Dike, and was due to the specific characteristics of that product. In contrast to the Sediment Log and GeoRidge, the Triangular Silt Dike permeability was very low, which resulted in a significant flow barrier and created a series of cascades between the ditch checks installed along the channel. This diminished the energy slope and in turn the shear stress along the bottom of the channel, which prevented erosion in the channel bed and enhanced sediment settling.

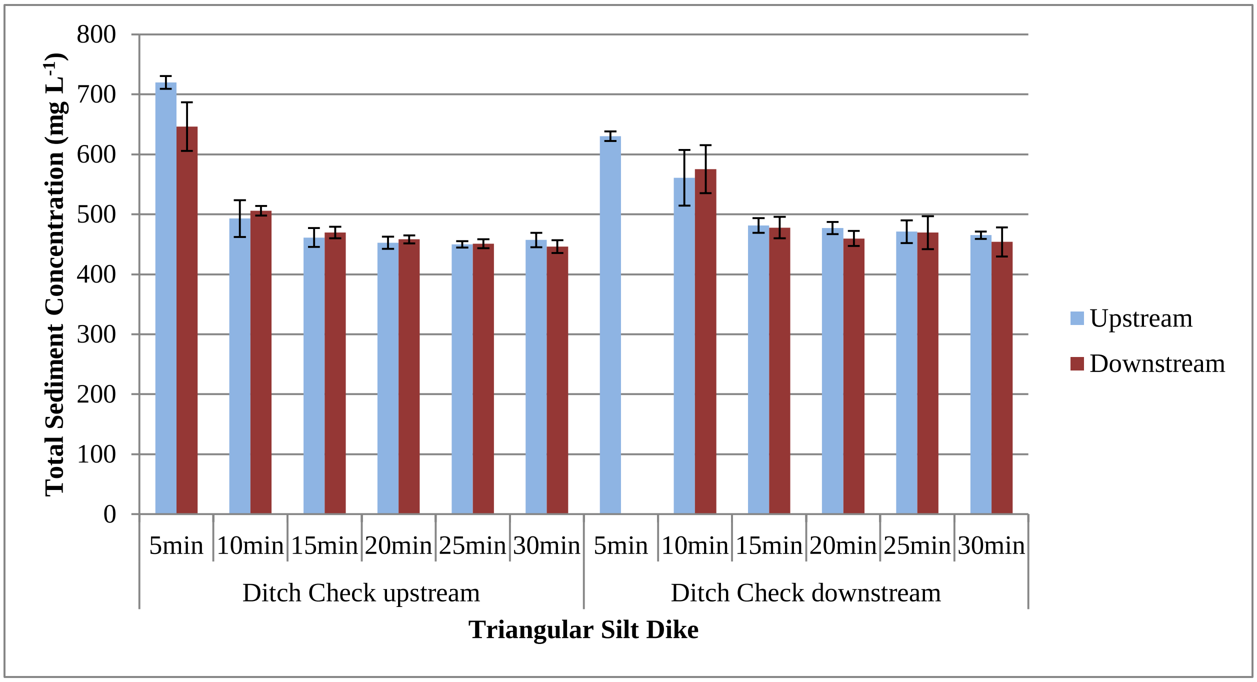


Figure 5.1. Average TSC values for Triangular Silt Dike under 10 L s^{-1} flow rate.

The TSC values under the 10 L s^{-1} flow rate for the GeoRidge product evaluation showed a similar trend to the results obtained for the Triangular Silt Dike. In this case, steady-state flow occurred approximately 3 minutes after the test started; TSC values decreased during the first 10 minutes of evaluation, thereafter stabilizing to a constant value. The manner in which this product retained sediment and prevented erosion in the channel bed differed from the Triangular Silt Dike. The GeoRidge ditch check primarily reduced flow velocities, causing sediment to settle upstream of the ditch check. Reduced water velocity also resulted in decreased downstream erosion. The average test results for GeoRidge ditch check product are presented in Figure 5.2.

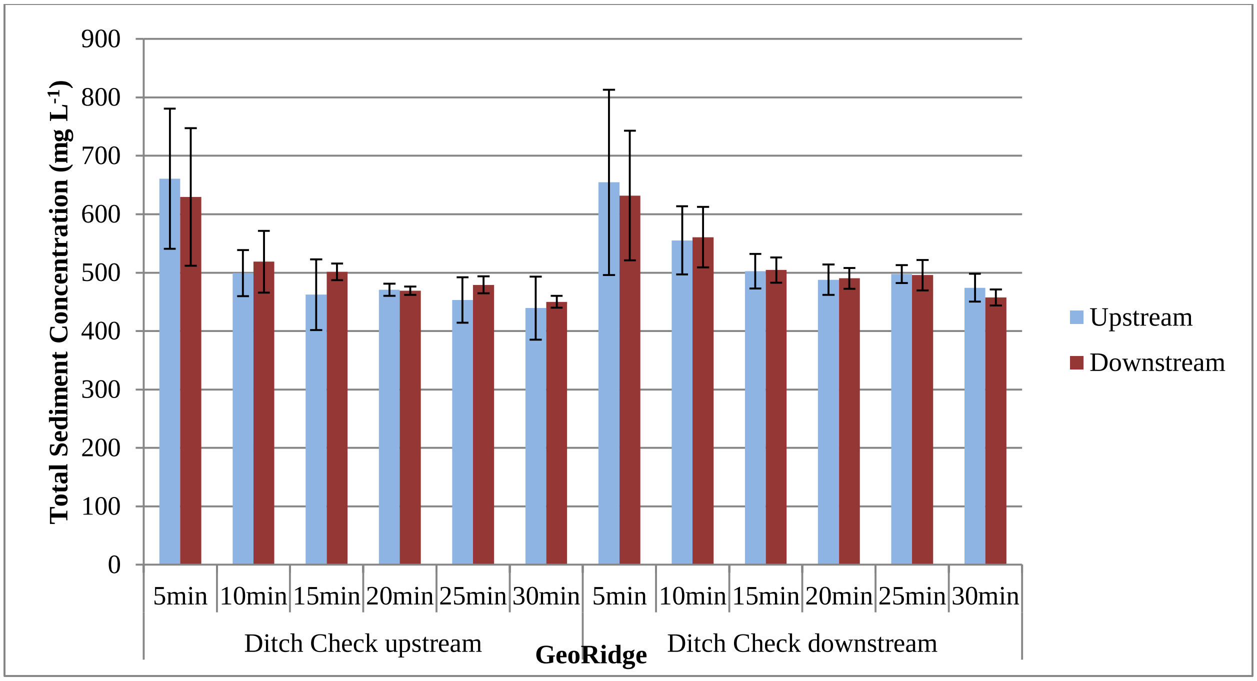


Figure 5.2. Average TSC values for GeoRidge under 10 L s^{-1} flow rate.

The Sediment Log results under the 10 L s^{-1} flow rate (Figure 5.3) showed substantially higher TSC values throughout the entire test. The Sediment Log retained sediment and prevented channel bed erosion in a similar manner to the GeoRidge product. The Sediment Logs exhibited a lower permeability than GeoRidge, which dissipated more flow energy, augmented sediment settling upstream of the check dams, and minimized erosion downstream of the ditch check. The discrepancy in higher TSC obtained for the Sediment Log than GeoRidge, however, can be mainly explained by the flow undercutting that occurred during evaluation, which is discussed in Section 5.1.2.

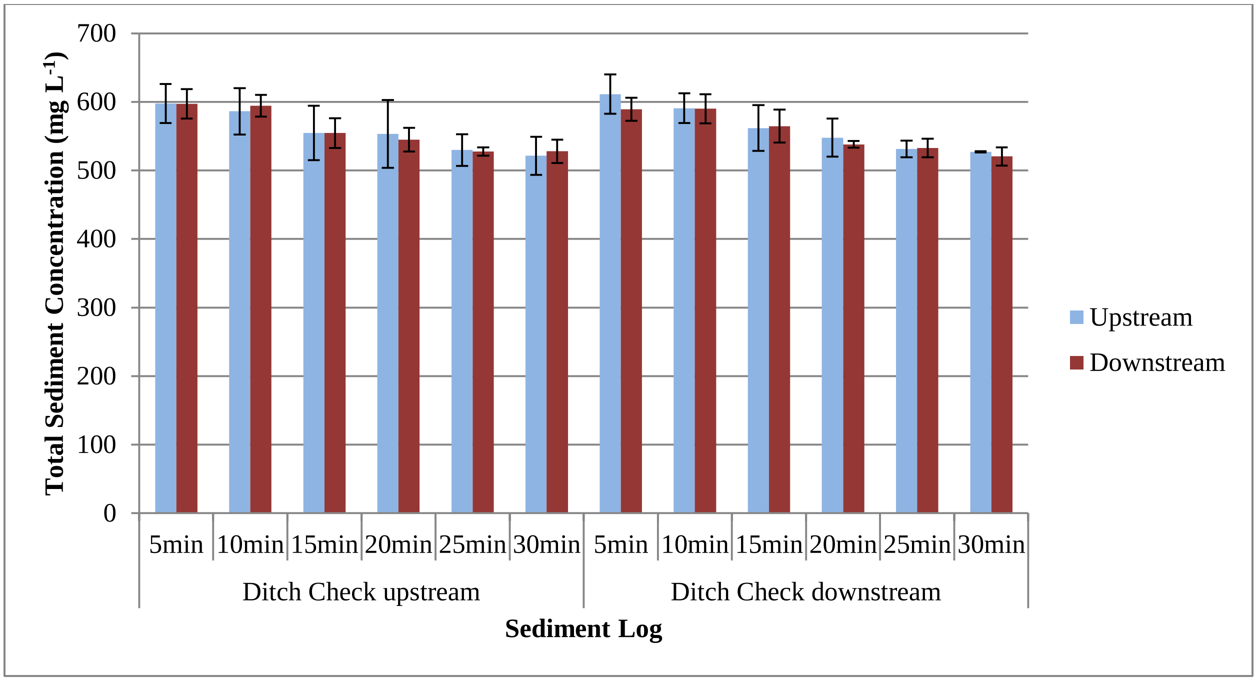


Figure 5.3. Average TSC values for Sediment Log under 10 L s^{-1} flow rate.

In order to perform a statistical comparison of the three ditch check products, the total soil loss was computed. This was calculated using the average TSC value over each five-minute period during testing, while discarding the first five minutes of each test to ensure steady state flow conditions. The resulting values were used to compare total channel soil losses between each product. The average soil losses for the three different ditch check products are presented in Figure 5.4. The difference in total soil loss between the Triangular Silt Dike and GeoRidge were statistically insignificant, but the Sediment Log soil loss was significantly higher than each of the other two products.

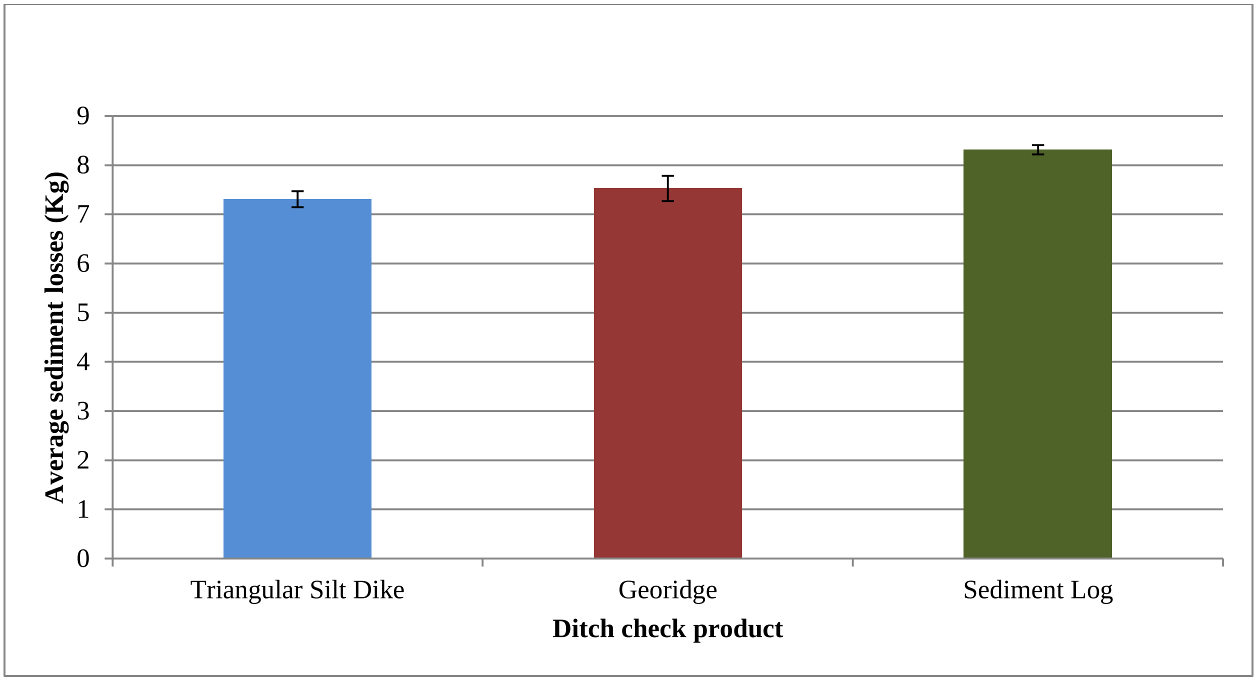


Figure 5.4. Average testing channel soil loss under 10 L s^{-1} flow rate.

The average TSC results obtained from the 7.5 L s^{-1} medium flow for all ditch check products are presented in Figure 5.5 through Figure 5.7. The TSC reduction exhibited the same trend as that observed for the high flow rate. Steady-state flow on the downstream side of the downstream Triangular Silt Dike occurred approximately 10 minutes after the test began (as in the high flow test), while for the GeoRidge and Sediment Log products, steady-state flow was reached around 3 minutes after testing started.

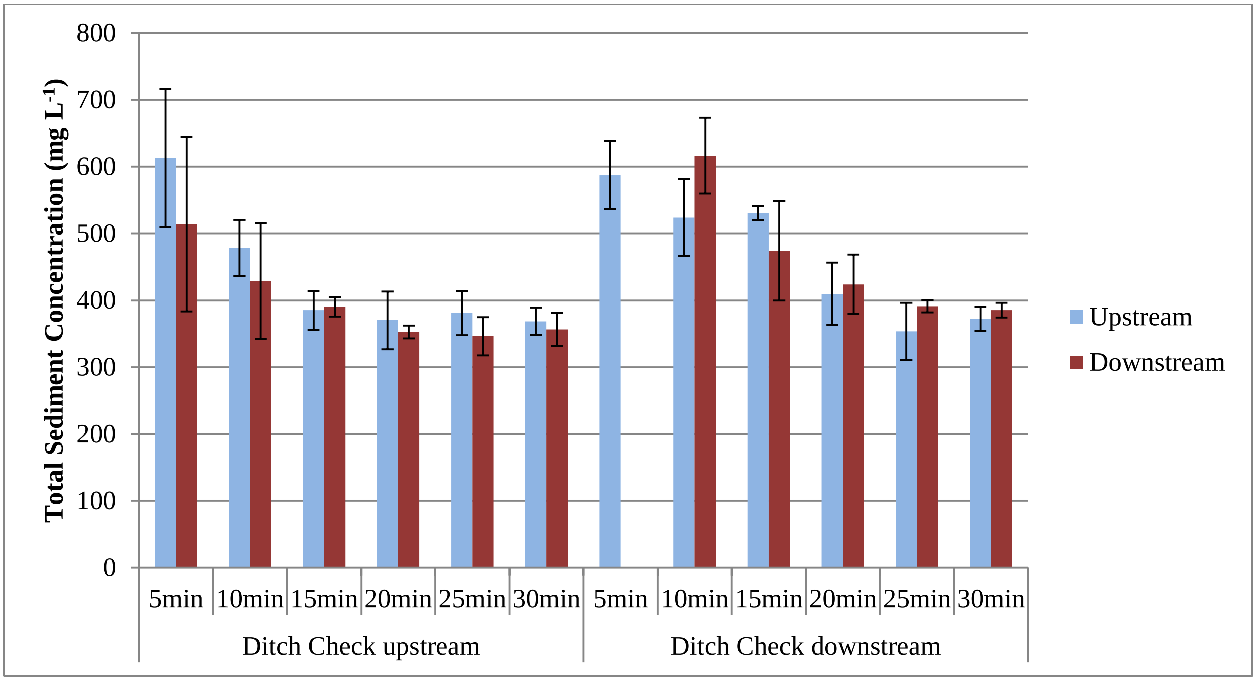


Figure 5.5. Average TSC values for Triangular Silt Dike under 7.5 L s^{-1} flow rate.

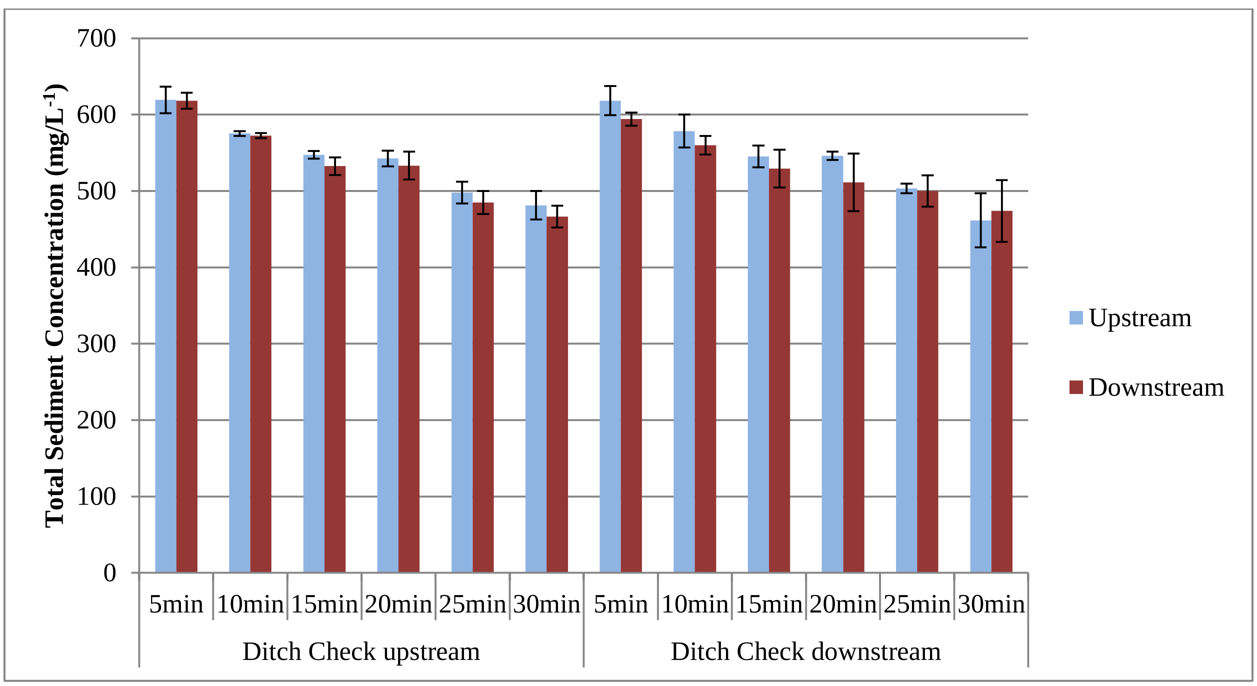


Figure 5.6. Average TSC values for GeoRidge under 7.5 L s^{-1} flow rate.

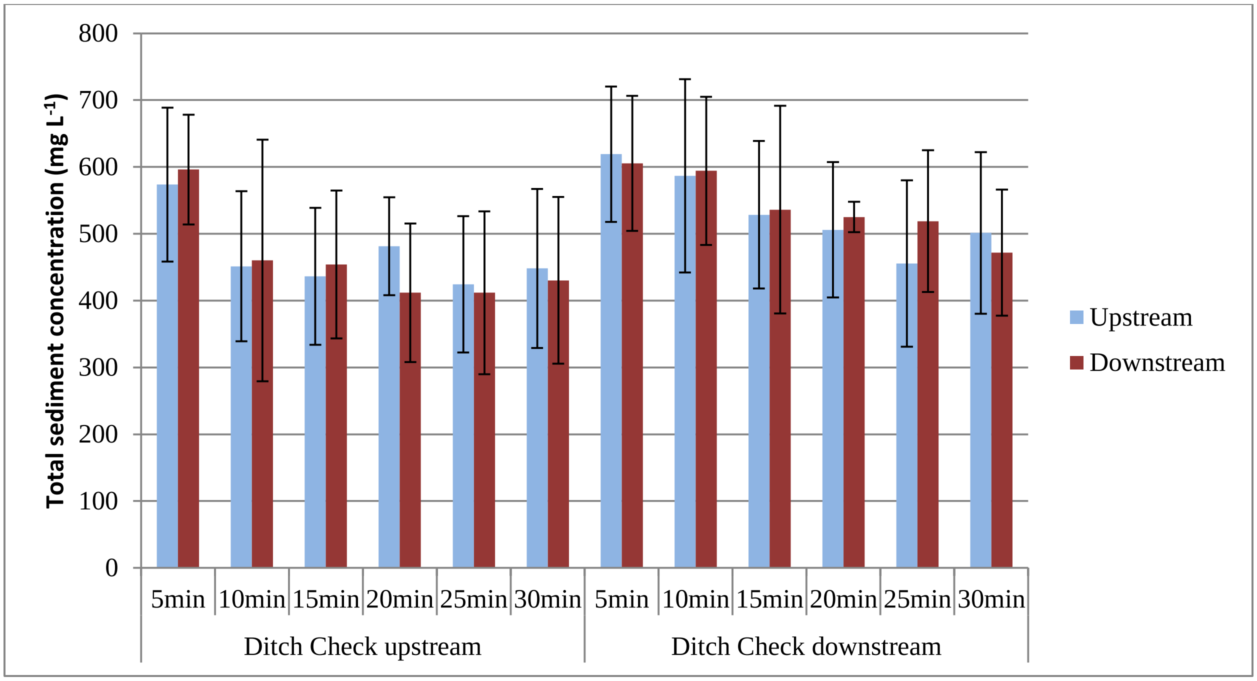


Figure 5.7. Average TSC values for Sediment Log under 7.5 L s^{-1} flow rate.

The sediment yield obtained for the 7.5 L s^{-1} test was significantly smaller than the yield under 10 L s^{-1} for the three ditch check products evaluated. The average total sediment losses obtained during evaluation of the three products are presented in Figure 5.8.

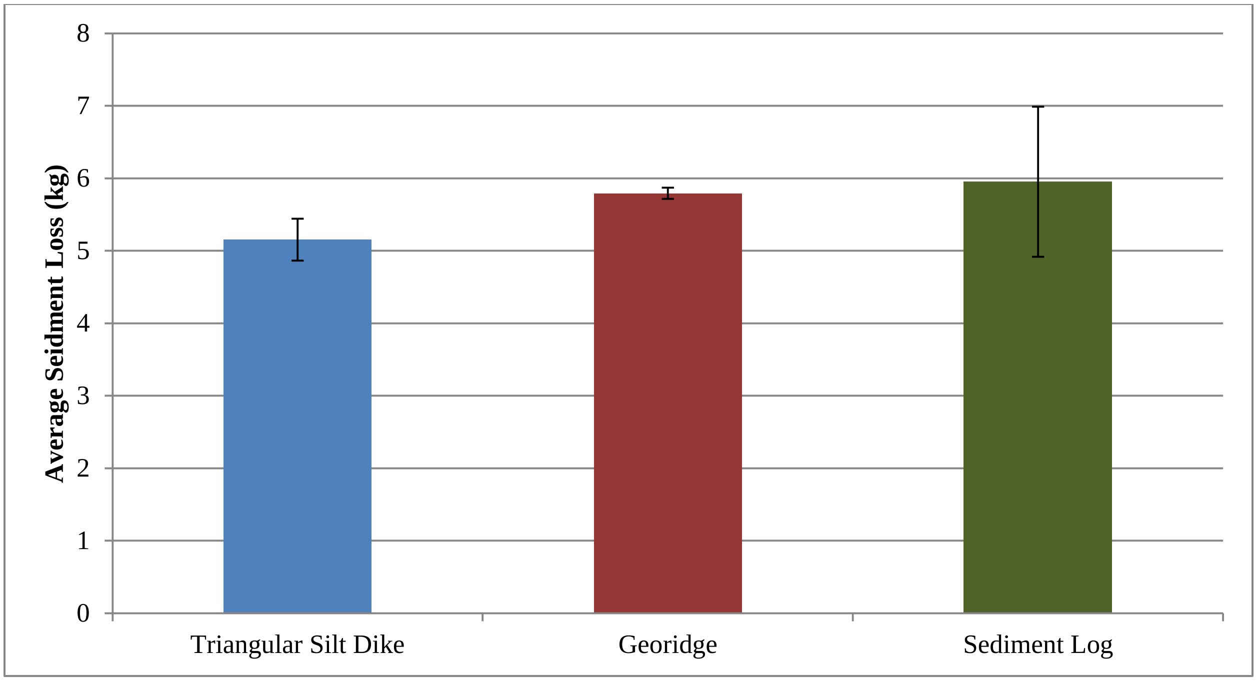


Figure 5.8. Average testing channel soil loss under 7.5 L s^{-1} flow rate.

The last set of tests was performed under low flow conditions of 5 L s^{-1}. Steady-state flow occurred after approximately 15 minutes for the Triangular Silt Dike, while it was reached in less than 5 minutes for the GeoRidge and Sediment Log.

The fact that steady state was not reached until after 15 minutes considerably affected the final results for the Triangular Silt Dike; grab samples could not be taken during the first 10 minutes, and the stable TSC trend observed under the previous two flow conditions was barely observed at the downstream side of the downstream ditch check. Failure to adequately consider this behavior could lead to erroneous interpretation of the results. The average TSC values obtained from the 5 L s^{-1} testing are presented in Figure 5.9 through Figure 5.11.

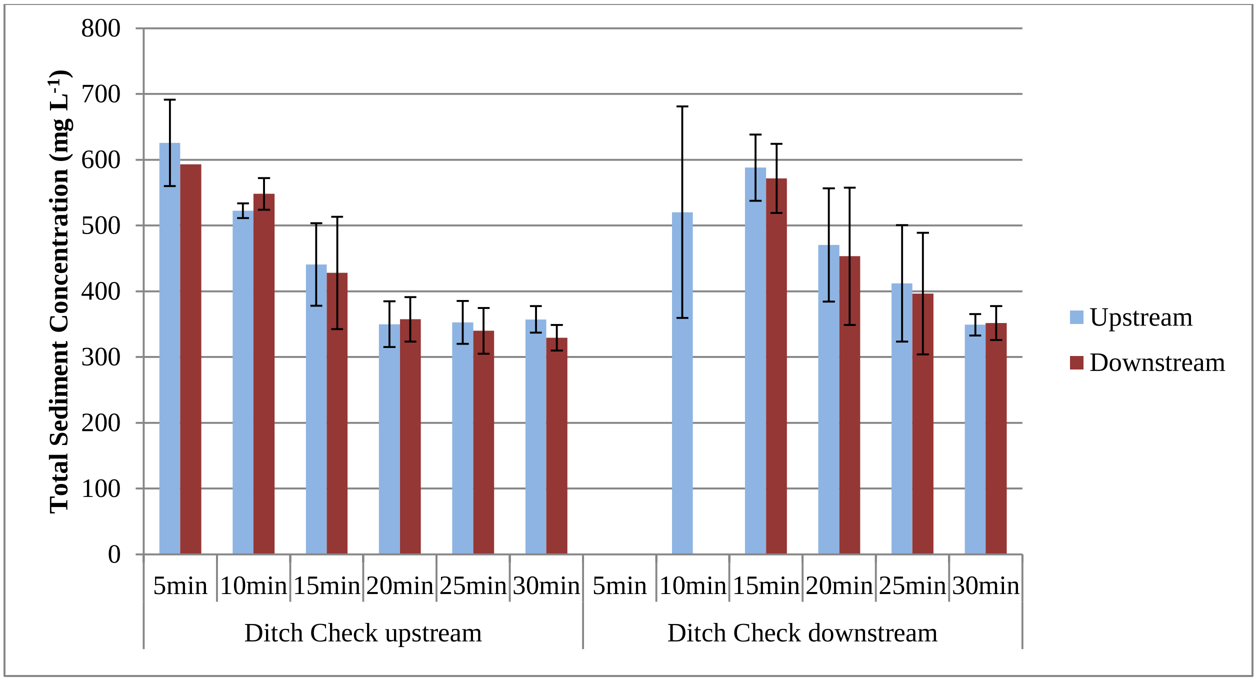


Figure 5.9. Average TSC values for Triangular Silt Dike under 5 L s^{-1} flow rate.

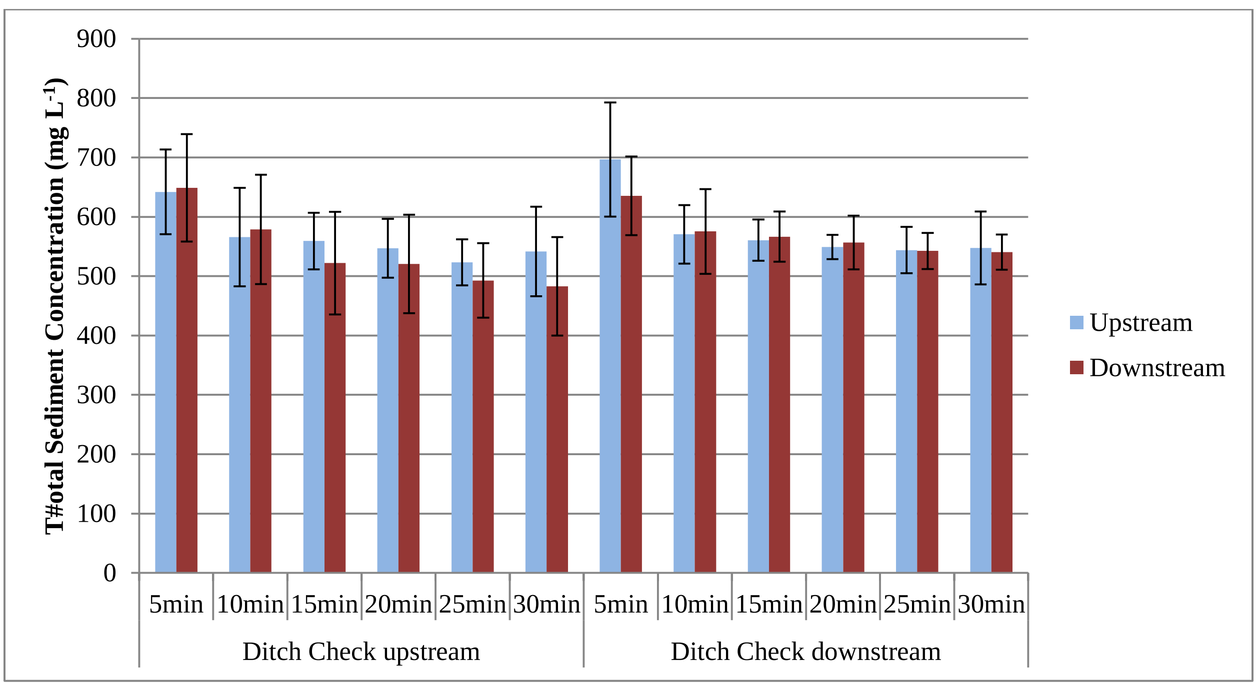


Figure 5.10. Average TSC values for GeoRidge under 5 L s^{-1} flow rate.

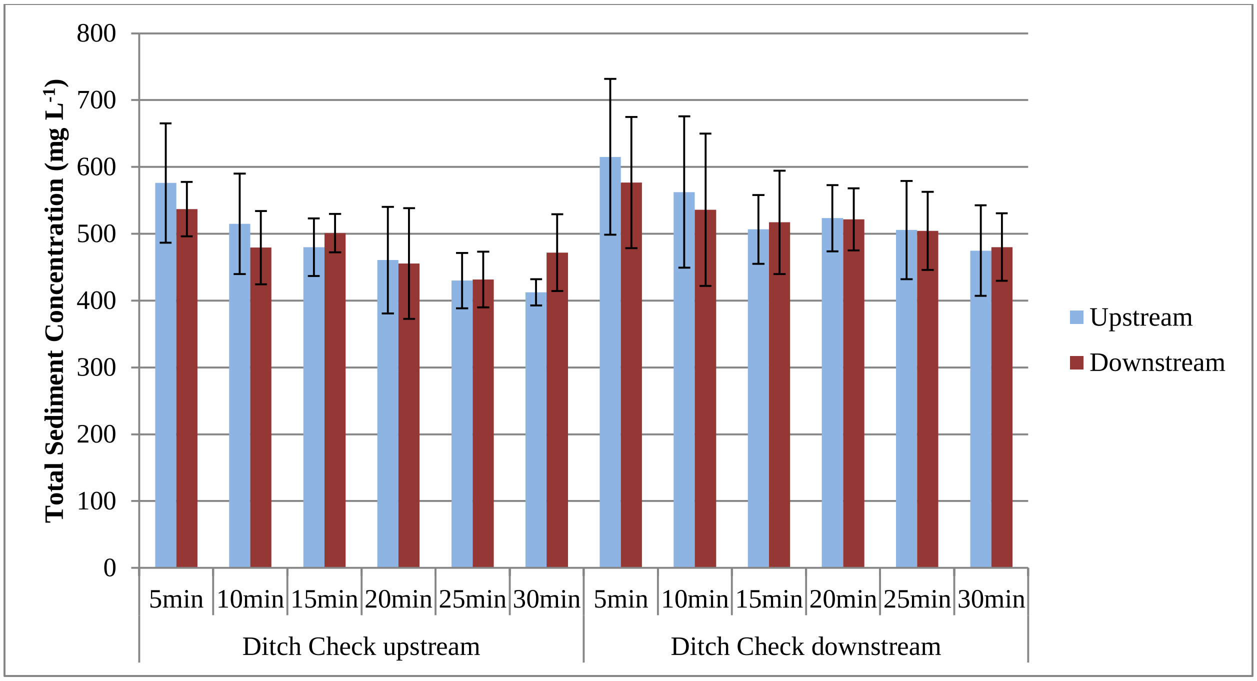


Figure 5.11. Average TSC values for Sediment Log under 5 L s^{-1} flow rate.

The total channel bed soil loss was significantly lower for the Triangular Silt Dike when compared to the GeoRidge and Sediment Log. Soil loss was also lower for all products when compared to the results obtained under higher flow rates. The total sediment yield was significantly smaller, because steady-state flow was reached approximately 15 minutes after the test started; hence, the total sediment yield was only computed for 15 minutes, while in all other evaluations it was calculated for the last 20 minutes of testing. This prevents a reliable comparison of the Triangular Silt Dike results under 5 L s^{-1} with the other two products evaluated.

The average soil loss obtained was also observed to be significantly smaller under low flow than medium flow for three ditch check products evaluated. There was no significant difference between the performance of the GeoRidge and Sediment Log, but comparison with the Triangular Silt Dike could not be performed. Figure 5.12 shows the total channel bed soil loss for all three products under a flow condition of 5 L s^{-1}.

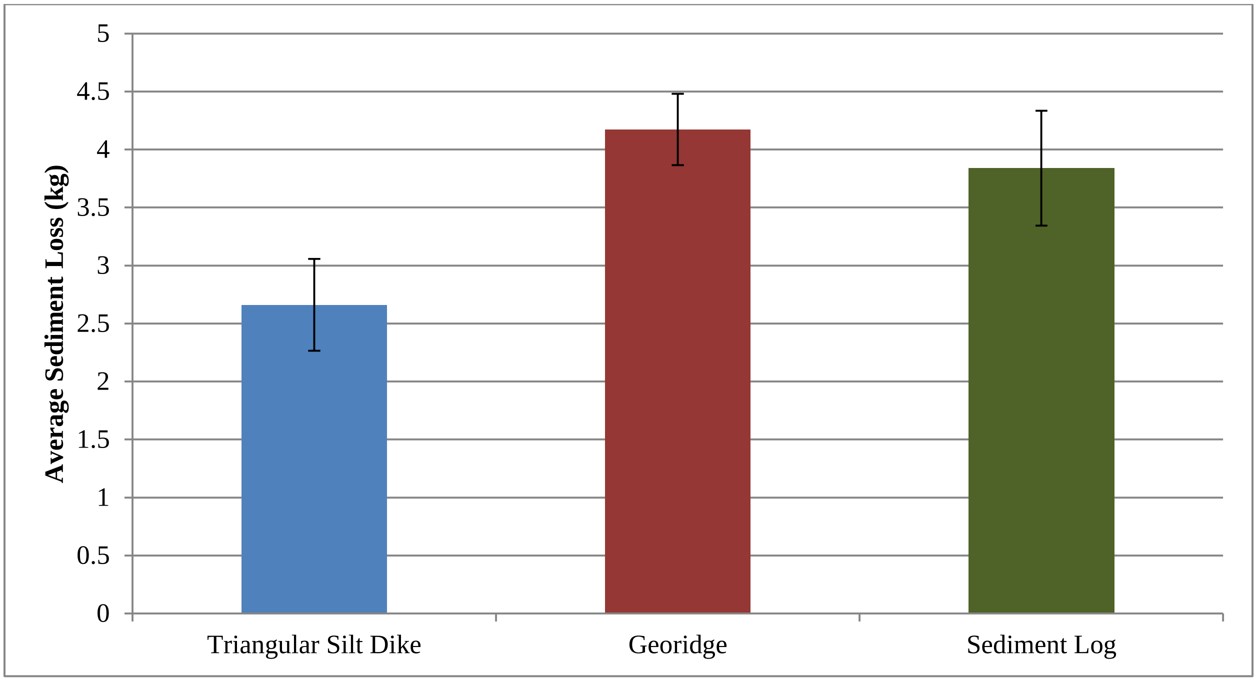


Figure 5.12. Average testing channel soil loss under 5 L s^{-1} flow rate.

The total average soil loss yielded from the product evaluations with three replications per test are presented in Table 5.1.

Table 5.1. Average channel bed soil loss for all products and flow rates.

Flow rate	Product	Average Sediment Yield (kg)
10 L s^{-1}	**Triangular Silt Dike**	7.308 $\pm$ 0.162
	GeoRidge®	8.313 $\pm$ 0.096
	Sediment Log	7.525 $\pm$ 0.254
7.5 L s^{-1}	**Triangular Silt Dike**	5.155 $\pm$ 0.290
	GeoRidge®	5.793 $\pm$ 0.078
	Sediment Log	5.954 $\pm$ 1.035
5 L s^{-1}	**Triangular Silt Dike**	2.660 $\pm$ 0.396
	GeoRidge®	4.172 $\pm$ 0.307
	Sediment Log	3.838 $\pm$ 0.494

5.1.2 Statistical Analysis of Ditch Check Product Evaluation

The low degree of variability among the replications permitted an accurate statistical analysis of the results obtained from the product evaluations. Welch's t-test was performed to compare the performance among the products. This test allowed comparison of the performance between paired product data to gauge how likely two products' results were drawn from the same population and determine whether the products performed the same. A test at the 90% confidence level was conducted to compare performance between evaluations. The *p*-values obtained for the paired Welch's t-test are provided in Table 5.2 through Table 5.4 for the 10, 7.5 and 5 L s^{-1} flow conditions, respectively.

Applying Welch's t-test to results from the 10 L s^{-1} flow condition indicated that the Triangular Silt Dike ditch check product performed significantly better than the Sediment Log ditch check product, while there was no significant difference when compared to the GeoRidge. Comparing results from the GeoRidge and Sediment Log evaluations indicated that GeoRidge products performed significantly better. Hence, one could confidently state that in terms of total sediment retention, the performance of the Triangular Silt Dike and GeoRidge was similar and significantly better than the Sediment Log.

Table 5.2. Average soil loss *p*-values for pairwise comparison under 10 L s-1 flow rate.

	Triangular Silt Dike	**GeoRidge**	**Sediment Log**
Triangular Silt Dike		0.376	0.004
GeoRidge	0.38		0.035
Sediment Log	0.004	0.035	

The statistical analysis results from comparing the three products under 7.5 L s^{-1} flow rates differed slightly from that of the high flow evaluation. In this case, there was no significant difference between the Triangular Silt Dike and the Sediment Log or between the Sediment Log and the GeoRidge, but Welch's t-test did indicate that the Triangular Silt Dike performed significantly better than the GeoRidge. Even though the average soil loss obtained from the GeoRidge evaluation was smaller than that of the Sediment Log, the statistical analysis showed a significant difference only between the Triangular Silt Dike and GeoRidge and not the Triangular Silt Dike and Sediment Log. This was due to the larger variance obtained from the Sediment Log evaluation and the small variance from the GeoRidge evaluation. In order to overcome this issue, a larger number of replications would be necessary for the statistical analysis.

Table 5.3. Average soil loss *p*-values for pairwise comparison under 7.5 L s^{-1} flow rate.

	Triangular Silt Dike	GeoRidge	Sediment Log
Triangular Silt Dike		0.054	0.312
GeoRidge	0.05		0.813
Sediment Log	0.312	0.813	

The results obtained from the evaluation under 5 L s^{-1} flow rates were inconclusive since the Triangular Silt Dike ditch check product could not be compared with the other two products. The total soil loss computed from the Triangular Silt Dike was less than the soil loss for the other two products largely because steady-state flow was not reached during the initial 10 minutes of the Triangular Silt Dike evaluation, which prevented collection of grab samples and produced a lower sediment yield. The statistical analysis of the other two products, however, showed no significant difference between the Sediment Log and GeoRidge performance.

Table 5.4. Average soil loss *p*-values for pairwise comparison under 5 L s^{-1} flow rate.

	Triangular Silt Dike	GeoRidge	Sediment Log
Triangular Silt Dike		0.008	0.034
GeoRidge	0.008		0.387
Sediment Log	0.034	0.387	

The total sediment loss computed for the three ditch check products showed a noticeable difference between the different flow rates used during evaluation. Hence, the average TSC, after stabilization was reached, obtained for the different flow rate conditions were compared and discussed individually for each product. The average TSC, after stabilization was reached, were compare and their results are displayed in Table 5.5.The statistical test used for this comparison was Welch's t-test with a confidence level of 90%. The results of these statistical comparisons are provided in Table 5.6 for the Triangular Silt Dike, Table 5.7 for the GeoRidge, and Table 5.8 for the Sediment Log.

Table 5.5. Average TSC, after stabilization was reached, for all products and flow rates.

Flow rate	Product	Average TSC (mg L^{-1})
10 L s^{-1}	**Triangular Silt Dike**	487.24 ± 51.32
	GeoRidge®	501.70 ± 42.66
	Sediment Log	549.21 ± 29.56
7.5 L s^{-1}	**Triangular Silt Dike**	458.21 ± 96.72
	GeoRidge®	514.92 ± 38.65
	Sediment Log	529.25 ± 99.00
5 L s^{-1}	**Triangular Silt Dike**	443.39 ± 107.52
	GeoRidge®	556.31 ± 41.56
	Sediment Log	511.83 ± 65.18

The p-values obtained after performing this statistical test for the Triangular Silt Dike evaluation results revealed no significant difference in average TSC values between the different flow rates. Hence, the flow rate did not seem to significantly affect the average TSC values for that particular product.

For GeoRidge evaluation, the resulting p-values indicated no significant difference between the average TSC under the 10 and 7.5 L s^{-1} rates, while there was a significant difference both between the average TSC under the 10 and 5 L s^{-1} flow rates and between the average TSC under the 7.5 and 5 L s^{-1} flow rates. The statistical analysis of results for the Sediment Log showed no significant difference in the average TSC values either between the 10 and 7.5 L s^{-1} rates or between the 7.5 and 5 L s^{-1} flow rates. There was a significant difference between the values under 10 and 5 L s^{-1} flow rates, however, which indicated that the average TSC under 10 L s^{-1} was significantly greater than that under 5 L s^{-1}.

Table 5.6. Average TSC *p*-values for pairwise comparison of Triangular Silt Dike results under all flow rates.

	10 L s^{-1}	**7.5 L s^{-1}**	**5 L s^{-1}**
10 L s^{-1}		0.316	0.213
7.5 L s^{-1}	0.316		0.713
5 L s^{-1}	0.213	0.713	

Table 5.7. Average TSC *p*-values for pairwise comparison of GeoRidge results under all flow rates.

	10 L s^{-1}	**7.5 L s^{-1}**	**5 L s^{-1}**
10 L s^{-1}		0.382	0.001
7.5 L s^{-1}	0.382		0.009
5 L s^{-1}	0.001	0.009	

Table 5.8. Average TSC *p*-values for pairwise comparison of Sediment Log results under all flow rates.

	10 L s^{-1}	**7.5 L s^{-1}**	**5 L s^{-1}**
10 L s^{-1}		0.465	0.057
7.5 L s^{-1}	0.465		0.574
5 L s^{-1}	0.057	0.574	

Overall, the results did not show a strong relationship between flow rate and sediment concentration over the 5 to 10 L s^{-1} range. For the same comparison performed with a 95% confidence level, there was only a significant difference between the average TSC values for the GeoRidge product under the 10 and 5 L s^{-1} flow rates.

In order to account for the sequential testing of replications for a given flow rate without channel repreparation, Friedman's statistical test was performed for total soil loss. In this analysis, the unique pair of each flow rate and position in the testing sequence was treated as a unique block with a single observation. The null hypothesis was that no significant difference existed between the effects of all three products (apart from block effects), and the *p*-value obtained was 0.00432. Hence, the effect of at least one of the ditch check products was different from the others at the 99% confidence level.

Performing pairwise Friedman tests for the three products showed significant difference between the Triangular Silt Dike and Sediment Log and between the Triangular Silt Dike and the GeoRidge, with *p*-values of 0.0027 and 0.01963, respectively. Again, however, there was no significant difference found between the Sediment Log and GeoRidge effects at even the 90% confidence level, with a *p*-value of 0.7389. These results confirm the previous statistical analysis, which showed the Triangular Silt Dike to perform significantly better than the other two products in terms of total soil loss.

5.1.3 Field Observation Discussion

Sediment transport is a process that involves both suspended sediment and bed load transport. The process that yields the majority of soil displacement from its original position is bed load transport, which has a tremendous impact on long-term ditch stabilization. Ditch check products are intended to provide channel stabilization until vegetation can provide long-term channel soil protection. Prior to vegetation establishment, the soil in channels is highly erodible, and ditch check products are installed to prevent soil disturbance and reduce soil displacement.

Therefore, ditch check products should not only prevent sediment transport out of the construction site, but also ameliorate the negative effects that soil displacement has on long-term channel stabilization. After channel disturbance, ditch checks are installed and the channel bed is seeded to provide long term stabilization; if the soil is displaced from its original position, however, it will carry the seeds along with it, and the areas where soil displacement occurred will not be able to generate a vegetative cover for long-term channel protection.

Test observations, photographs taken before, during, and after product evaluation, and total sediment retention analysis were used to determine the product effectiveness in terms of channel bed disturbance and potential product failure during test performance. The upstream sides of both ditch checks in series were scanned to quantify the total sediment retained by the ditch checks. The scan covered an area measuring 2 m upstream of the ditch check and along the entire wetted width of the channel. Even though these results supported the visual observations, the results could not be used for product comparison. Ideally, the scan should be performed over the entire channel so that a complete mass balance can be performed to determine the total sediment leaving the area; this would also allow calculation of the volume of sediment displaced from its original position, and permit comparisons between different products. Profiling the entire channel was not feasible in this study due to equipment and time constraints at the time the product evaluations were performed. However, software for the laser scanning distance meter has subsequently improved, and profiling the entire channel can now be accomplished in future evaluations.

The pre-test and post-test scans were used to compute the total accumulated sediment volume in front of the downstream ditch check. The upstream ditch check was scanned as well, but only the one downstream was considered for analysis, because it was more representative of those found at a typical construction site. However, it was still considered important to take photographs and perform scanning for the upstream ditch check to evaluate any potential product failure.

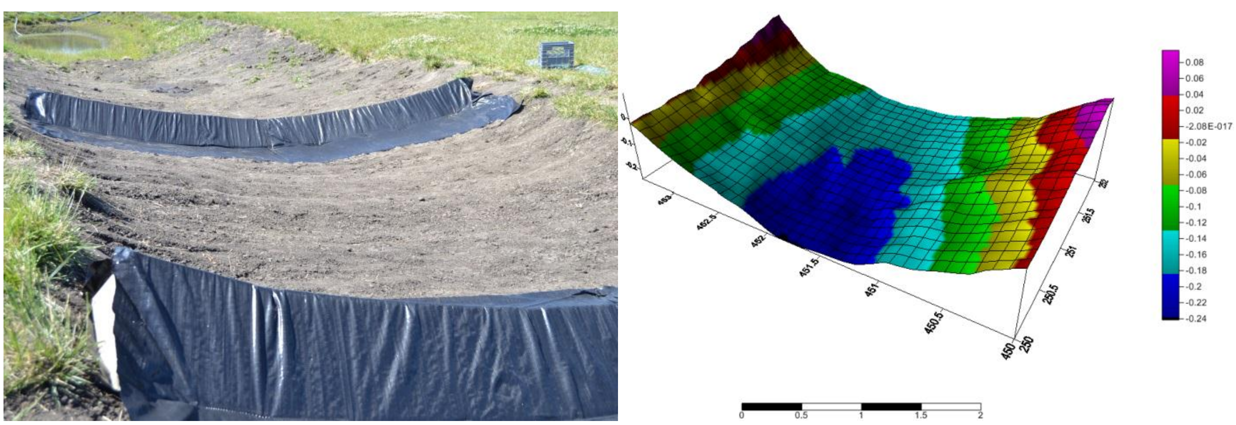
The total accumulated volume in front of the downstream ditch check was interpreted as the volume of soil displaced from its original position. This volume was calculated using the commercially available software SURFER. The laser scanning distance meter was used to take topographic measurements on a 10 cm by 10 cm grid of the area prior to the start of testing and after completion of each test. The grid of elevation measurements was then interpolated onto a surface using kriging. Once the surfaces of the scanned areas were obtained, the volume was computed by overlaying the surfaces.

Very little soil disturbance was observed under the three flow rates for the Triangular Silt Dike evaluation, and sediment accumulation in front of the Triangular Silt Dike was barely noticeable. On the other hand, soil disturbance and sediment accumulation were easily observed for both the Sediment Log and GeoRidge products under all three flow rates. The calculated volume of accumulated sediment in front of the downstream ditch check supported the visual observations recorded during testing. Therefore, the total volume of accumulated sediment was used as an estimate of channel bed disturbance, and results for all products and flow rates are presented in Table 5.9.

Table 5.9. Total volume of accumulated sediment (L) in front of downstream ditch check for all products and flow rates.

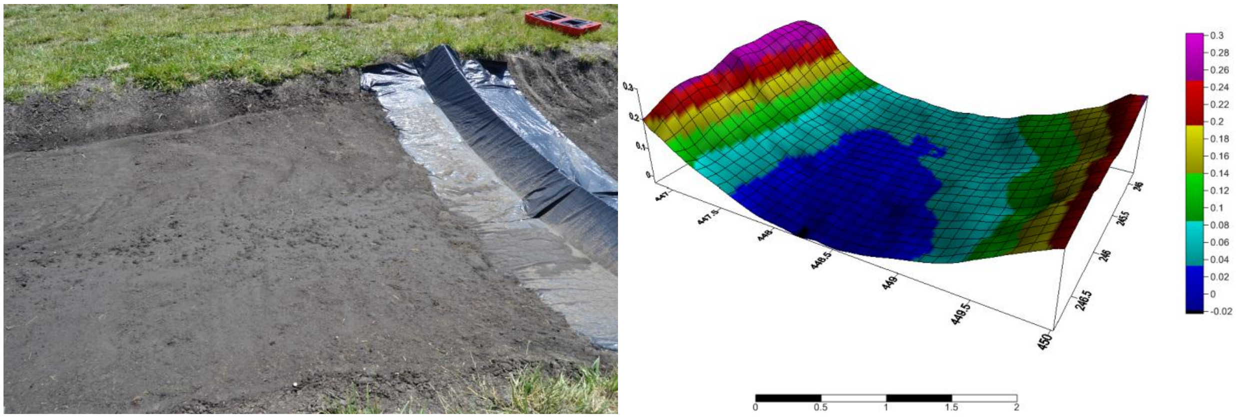
	10 L s^{-1} flow rate	7.5 L s^{-1} flow rate	5 L s^{-1} flow rate
Triangular Silt Dike	17.62	12.88	16.51
Sediment Log	31.08	28.59	25.72
GeoRidge	54.80	31.22	44.20

Photographs of the front side of the downstream ditch check and associated surface scans before and after testing under the 10 L s^{-1} flow rate are displayed for all three products in Figures 5.13 to 5.18. The photographs and surface plots for the 7.5 and 5 L s^{-1} flow rates can be found at Appendix B.



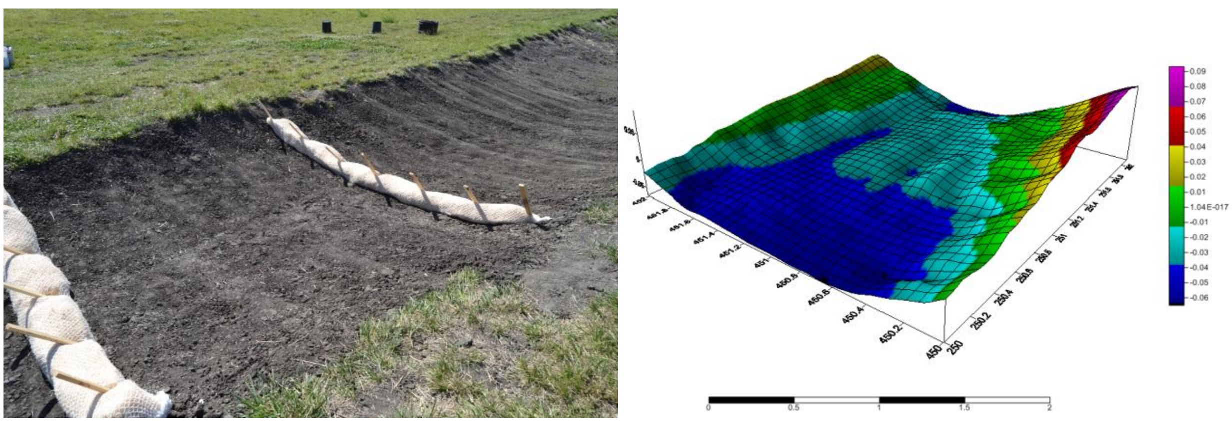
(a) **(b)**

Figure 5.13. (a) Photograph of downstream Triangular Silt Dike prior to testing under the 10 L s^{-1} flow rate. (b) Associated scanned profile for front side of downstream Triangular Silt Dike.



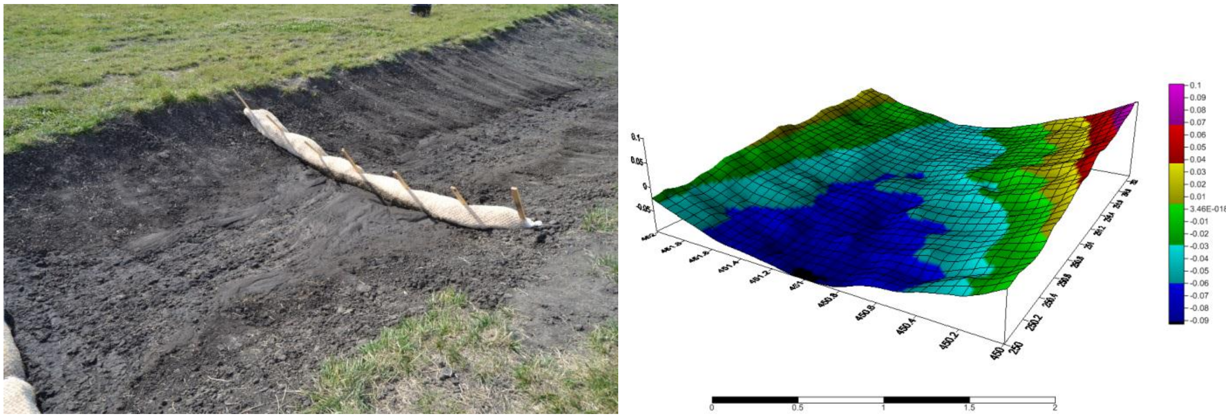
(a) (b)

Figure 5.14. (a) Photograph of downstream Triangular Silt Dike after testing under the 10 L s^{-1} flow rate. (b) Associated scanned profile for front side of downstream Triangular Silt Dike.



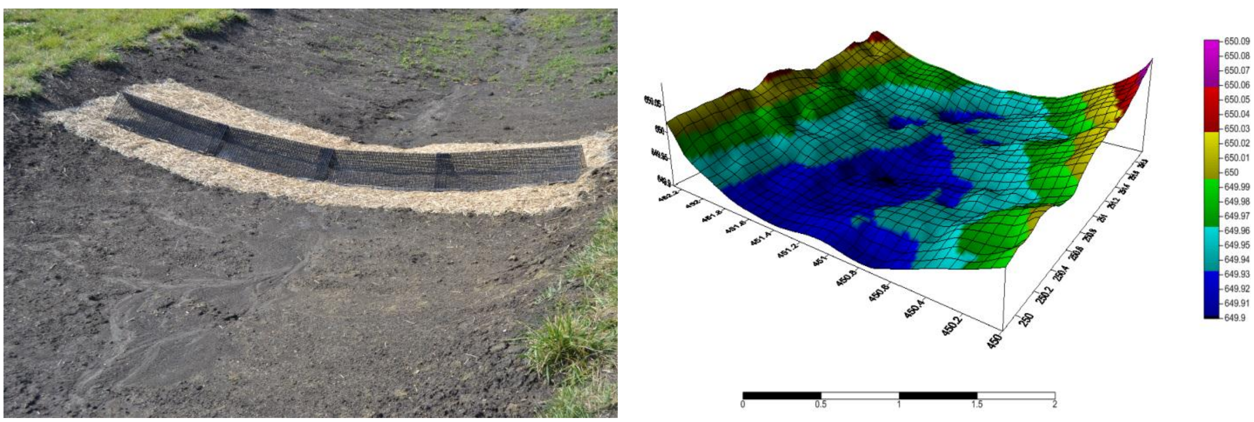
(a) (b)

Figure 5.15. (a) Photograph of downstream Sediment Log prior to testing under the 10 L s^{-1} flow rate. (b) Associated scanned profile for front side of downstream Sediment Log.



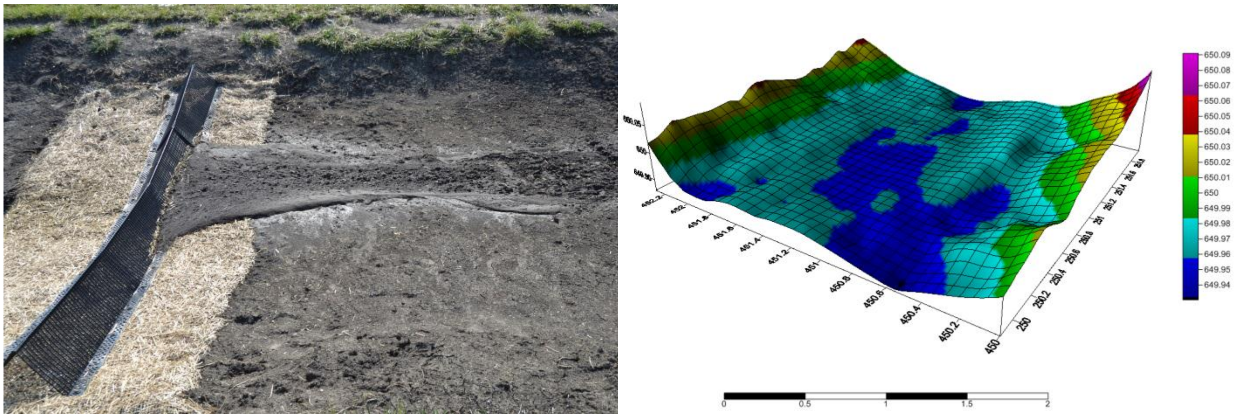
(a) **(b)**

Figure 5.16. (a) Photograph of downstream Sediment Log after testing under the 10 L s^{-1} flow rate. (b) Associated scanned profile for front side of downstream Sediment Log.



(a) **(b)**

Figure 5.17. (a) Photograph of downstream GeoRidge prior to testing under the 10 L s^{-1} flow rate. (b) Associated scanned profile for front side of downstream GeoRidge.



(a) (b)

Figure 5.18. (a) Photograph of downstream GeoRidge after testing under the 10 L s^{-1} flow rate. (b) Associated scanned profile for front side of downstream GeoRidge.

Product failure was not observed for any of the three products tested under the selected flow rates. Undercutting was only noticeable for the Sediment Log under the 10 and 7.5 L s^{-1} flow rate conditions, but was not severe enough to cause product failure. The undercutting observed for the Sediment Log ditch check product during the 10 L s^{-1} flow rate evaluation is displayed in Figure 5.19.

(a) (b)

Figure 5.19. (a) Sediment Log during 10 L s^{-1} flow rate product evaluation. (b) Sediment Log after 10 L s^{-1} flow rate product evaluation.

5.2 Erosion Control Blanket Evaluation

Soil samples were also taken from the erosion plots to determine the soil texture used for evaluation of the erosion control blankets. Future evaluations must be performed under the same soil and rainfall conditions in order to accurately compare the performance of different products.

The particle size analysis was done following the hydrometer method described Gee and Baude (1986). This method was a modification of the Day (1965) and ASTM (1985d) methods. The results of the analysis indicated that the erosion plots were composed of a silt-loam soil as defined by USDA soil texture classification, with 13.7% sand, 60.3% silt, and 26% clay.

5.2.1 Results and Discussion for Erosion Control Blanket Evaluation

Three replications and a bare control were evaluated on the erosion plots for each product using a simulated rainfall rate of 100 mm h^{-1} and test duration of 30 min. The erosion control blankets were replicated in plots one, three, and four for each of the products tested, and the bare control plot evaluation was performed in plot two with no replications.

Runoff began between 1 and 2.5 minutes after the start of rainfall for the erosion control blankets, while for the bare control plot the runoff started approximately 20 seconds after rainfall began. Runoff was observed to stop between 5 and 12 minutes after the rainfall ended for the erosion control blankets, while it did not stop until after 18 minutes for the bare control plot. The variability of runoff initiation and cutoff among the blankets may have resulted from different stages of soil saturation. Even though the soil was saturated prior to product evaluation to provide uniform and consistent soil saturation, the extremely dry soil conditions resulting from a severe regional drought during product testing in the summer of 2012 were likely to have substantially affected soil moisture conditions in the erosion plots.

Results for the three different erosion control blankets and control plot are shown in Table 5.10. The results presented are the average cumulative soil loss and average cumulative runoff obtained for the 30-minute duration of the experiments. The three erosion control blankets exhibited significantly less soil loss and cumulative runoff relative to the control. The results showed a total soil loss reduction of 81.21% for DS75, 79.5% for SC150 and 93.8% for Curlex I relative to the control. The total soil losses obtained from this study were relatively small when compared to results from other studies. Results obtained for the laboratory erosion control blanket evaluation by Beighley et al. (2009) showed relatively larger soil losses and total runoff. These differences in soil loss and total runoff were caused by the very fine droplet size of the rainfall and the application of rainfall to the plots prior to evaluation in order to initially saturate the soil and blankets. In some cases, the plot saturation procedure took more than three hours due to the low soil moisture content of the erosion plots resulting from the severe drought conditions, which consequently affected the total soil loss during performance evaluation.

Table 5.10. Summary of erosion control blanket evaluation results.

Erosion control treatment	**Slope**	**Average Soil loss (g)**	**Average Total Runoff (kg)**
SC150	2H:1V	420.85 ± 228.66	725.20 ± 90.38
DS75	2H:1V	385.44 ± 102.77	792.79 ± 156.24
Curlex I	2H:1V	127.38 ± 11.58	295.62 ± 42.95
None, Control plot	2H:1V	2049.49	1064.73

Welch's t-test was used to compare total soil loss from the erosion plots under the three different treatments and the control plot with a 90% confidence level. The *p*-values presented in Table 5.11 indicated no significant difference in soil loss when comparing SC150 to either DS75 or Curlex I. The results did show significantly less soil loss for the Curlex I when compared to

DS75, however, even though the average soil loss observed for DS75 was less than that for SC150; this was due to the large variance of the soil loss for the SC150 evaluation. The total soil loss was significantly greater for the control plot relative to all three of the erosion control blankets evaluated. The average soil loss for the different treatments and control plot are displayed in Figure 5.20.

Table 5.11. Total soil loss *p*-values for pairwise comparison of ECB treatments.

	SC150	DS75	Curlex I	Control Plot
SC150		0.824	0.156	0.006
DS75	0.824		0.047	0.0012
Curlex I	0.156	0.047		0.000012
Control Plot	0.006	0.001269	0.000012	

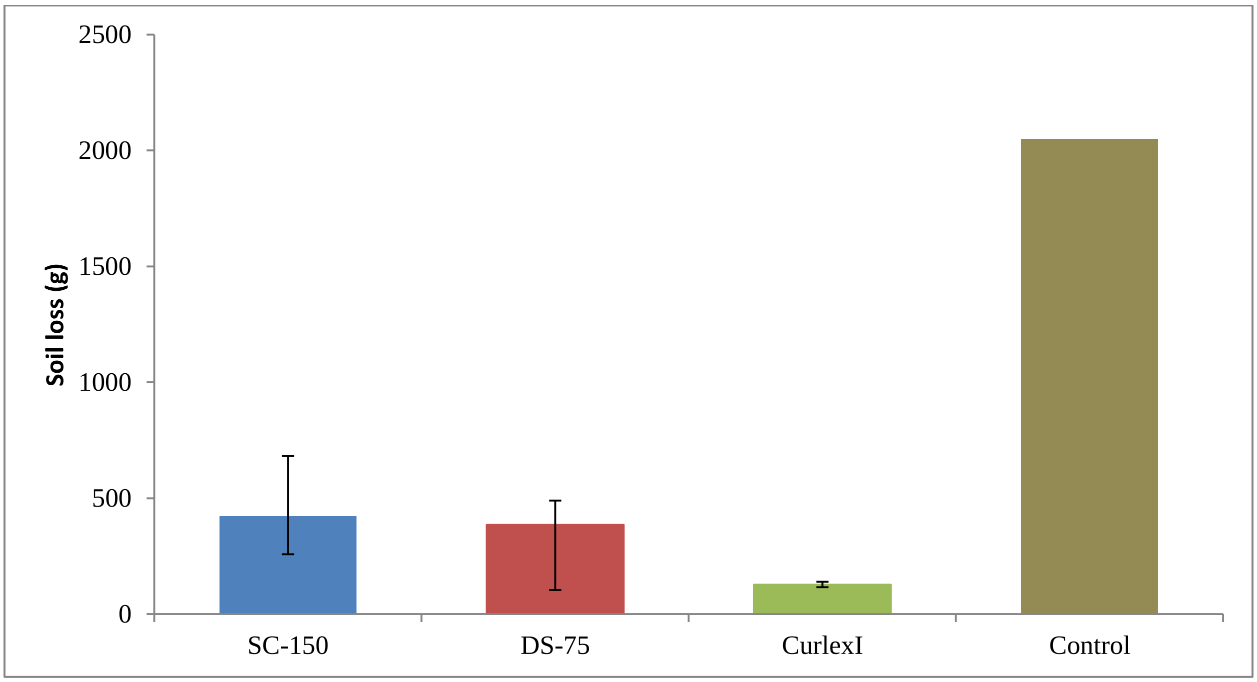


Figure 5.20. Average soil loss for erosion control blankets and the control plot, with minimums and maximums.

It was observed during pre-evaluation of the erosion control blankets that some materials were able to absorb a substantial amount of water when their moisture content was low. Once erosion control blankets had been installed on the erosion plots, they were then pre-wetted to minimize the effects of water absorption that could lead to smaller runoff rates and hence lower sediment yield, making product performance comparison more difficult. Even with plot pre-wetting, the total runoff obtained from Curlex I was significantly smaller than the other two blankets. The average total sediment concentrations of the grab samples taken during evaluation showed that the total sediment concentrations were similar for all three products (Figure 5.21); therefore, one could conclude that differences in total soil loss between the products was mainly due to the total runoff volume collected during evaluation.

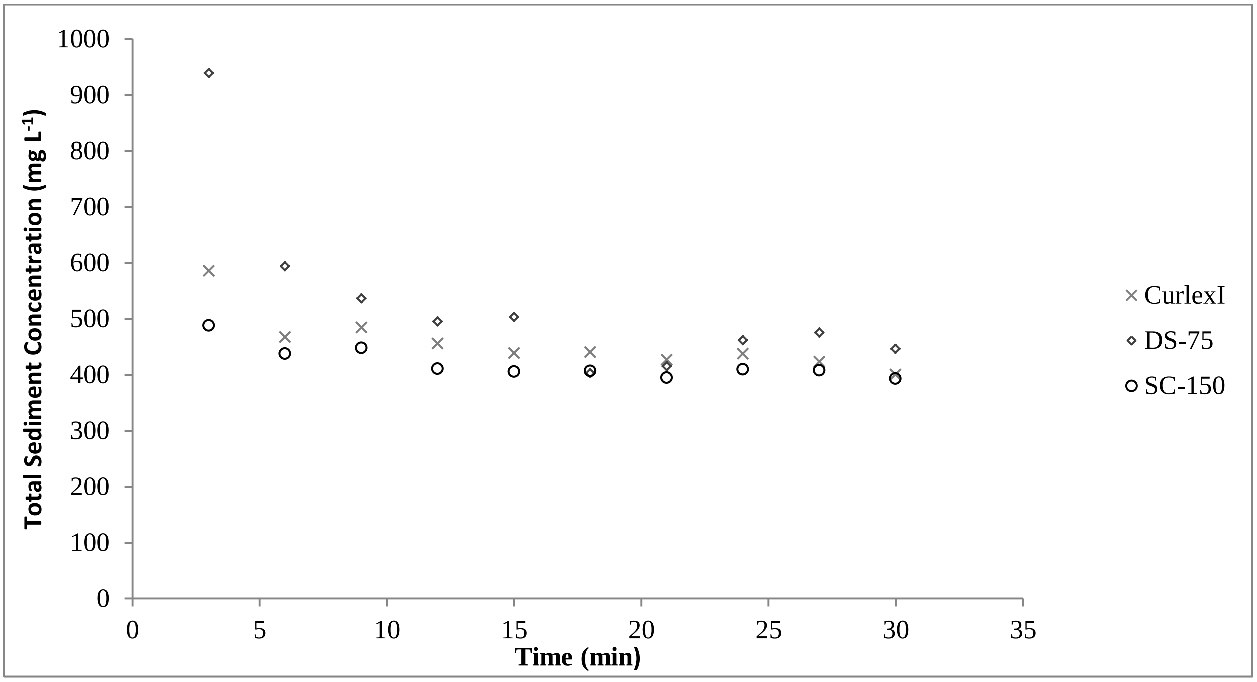


Figure 5.21. Average TSC values during erosion control blanket evaluation.

The substantial variability of total runoff collected among the erosion control blankets and the control plot made it necessary to perform a statistical analysis of total runoff between the different blankets and control plot, in addition to comparisons of the average soil loss. The runoff rates obtained for the three replications of SC150, DS75, Curlex I, and the control plot are presented in Figures 5.22 through 5.25, respectively. The total runoff collected from the SC150 evaluation yielded a relative runoff reduction of 31.89% relative to the control plot. A similar result was obtained for DS75, which produced a 25.54% runoff reduction relative to the control plot. The result from the Curlex I evaluation was much greater, with 72.23% relative runoff reduction. The differences in total runoff reduction observed between blankets, especially when comparing Curlex I to the other two products, can be explained by the water retention capability of the wood fibers that comprise the blankets.

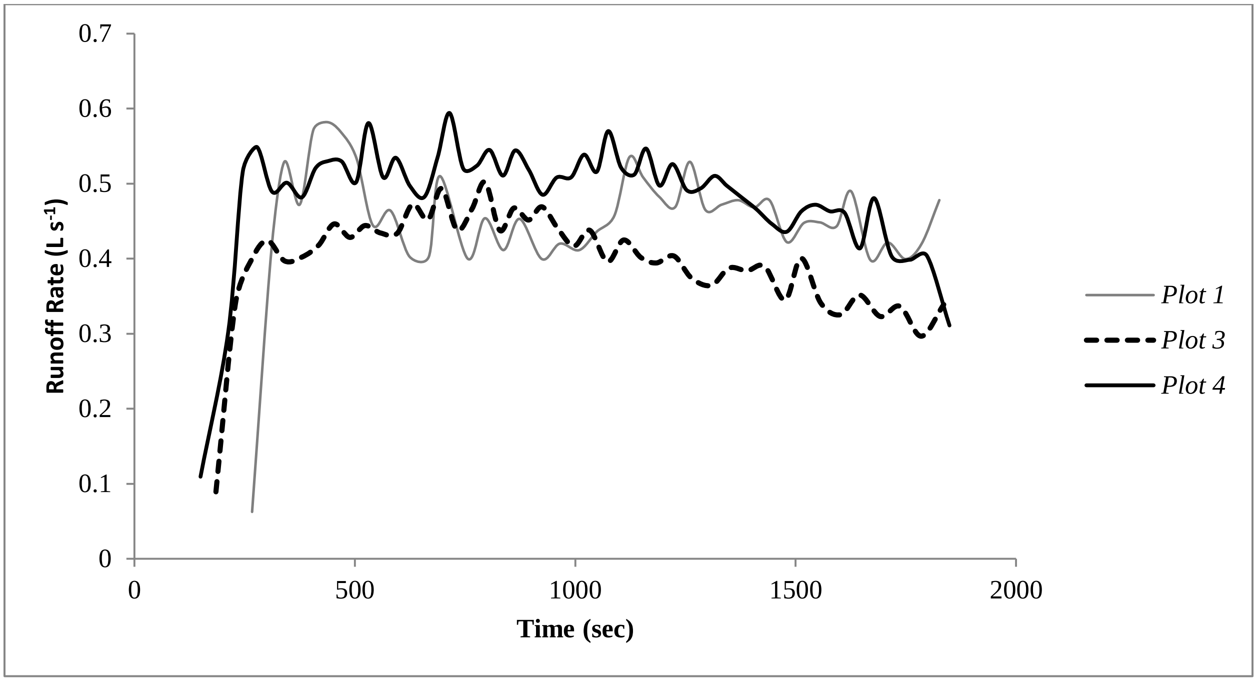


Figure 5.22. SC150 runoff rate for three replications.

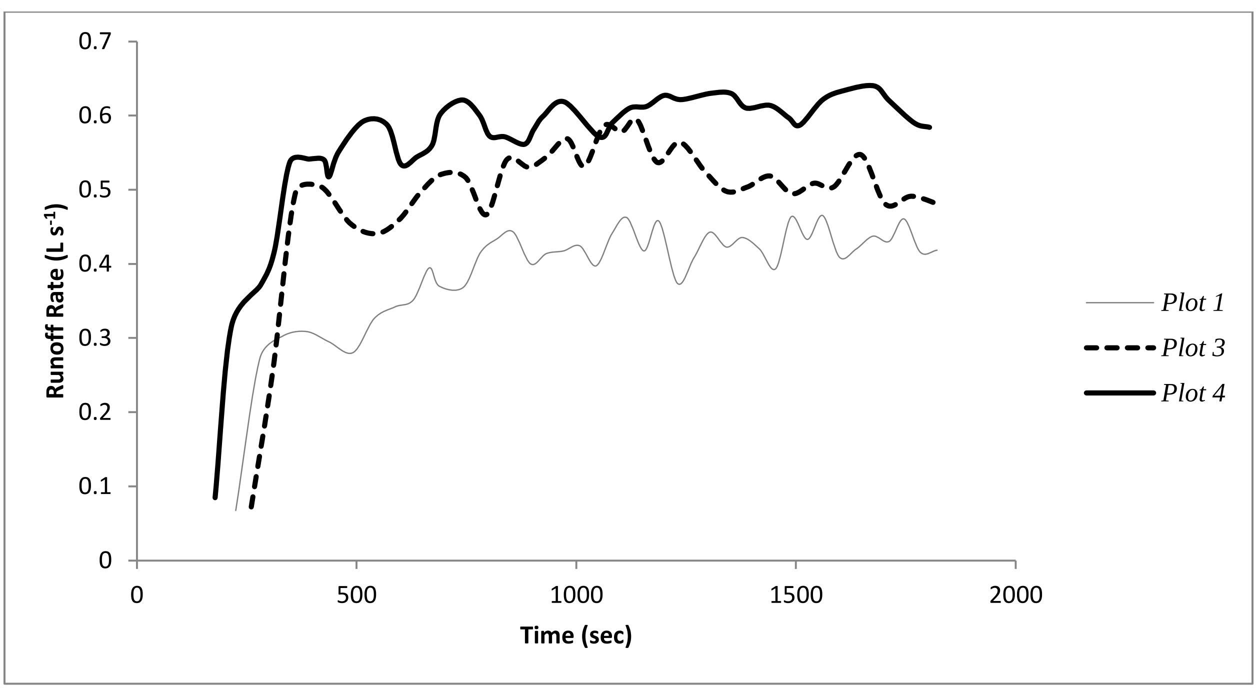


Figure 5.23. DS75 runoff rate for three replications.

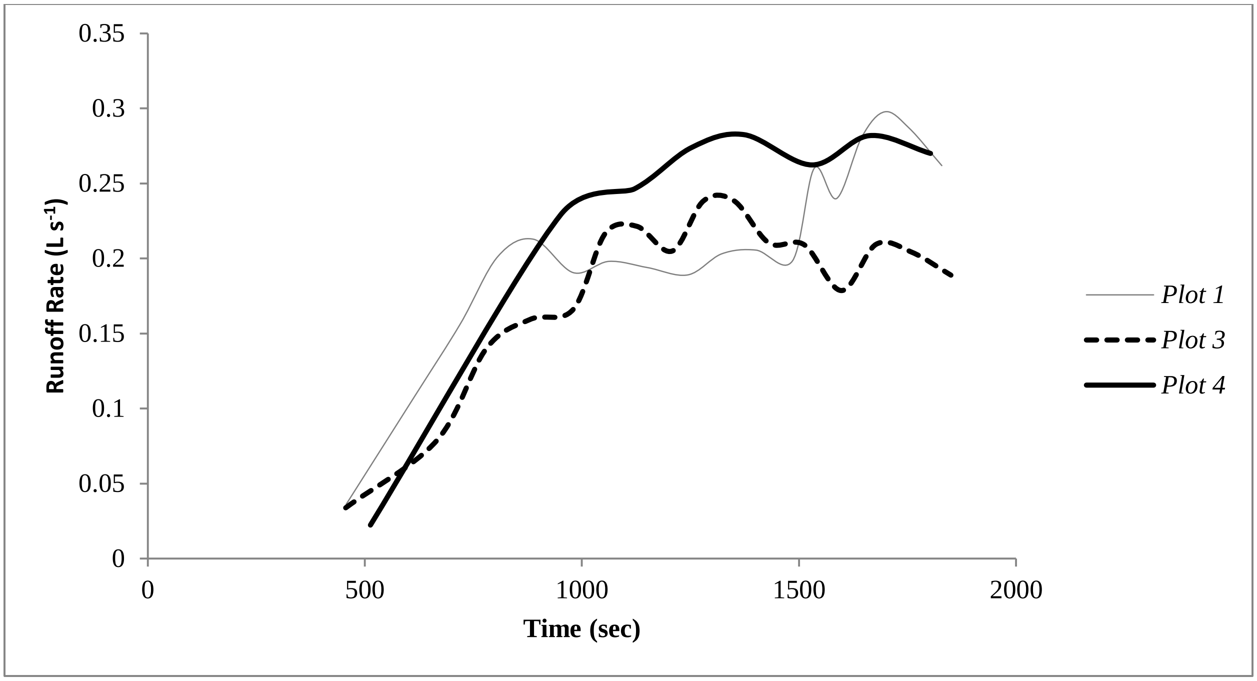


Figure 5.24. Curlex I runoff rate for three replications.

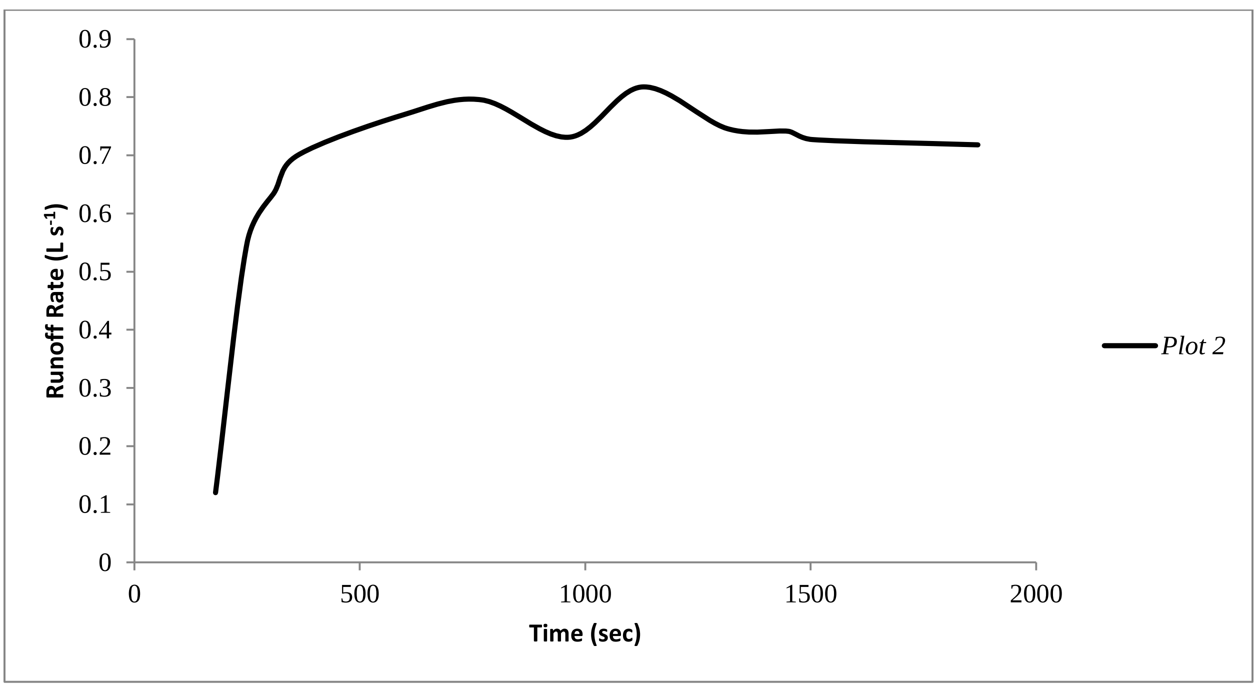


Figure 5.25. Bare control plot runoff rate.

Welch's t-test was also performed to statistically compare the total runoff collected from the erosion control blankets and the control plot. The *p*-values obtained from the statistical test are presented in Table 5.12. The results showed significantly less runoff collected from Curlex I than the other two erosion control blankets and the control plot at a 95% confidence level. The results also showed no significant difference between the DS75 and SC150 erosion control blankets, while both yielded significantly less runoff than the control plot at a 90% confidence level.

Table 5.12. Total runoff *p*-values for pairwise comparison of erosion plot treatments.

	SC150	DS75	Curlex I	Control Plot
SC150		0.56	0.01	0.02
DS75	0.56		0.02	0.09
Curlex I	0.01	0.02		0.001
Control Plot	0.02	0.09	0.001	

5.2.2 Field Observation Discussion

Visual observations were also documented during evaluation of erosion control blankets and the control plot. Photographs were taken after both plot preparation and product evaluation. Rill formation was only observed in the control plot, as shown in Figure 5.26, while firm conclusions could not be drawn as to soil disturbance beneath the erosion control blankets. Removal of the erosion control blankets required researchers to step over the blankets, which may have potentially obliterated any incipient rills. The small sediment quantity collected from the three erosion control blankets, however, indicated that rill formation was unlikely under the tested conditions. The impact of foot traffic over the erosion plots can be observed in Figure 5.27.

Figure 5.26. Bare control plot after erosion evaluation.

Figure 5.27. SC150 plot after erosion evaluation.

5.3 Relationship between Total Suspended Solids (TSS), Total Solids, and Turbidity

The direct measurement of TSS cannot be performed in the field, as it is necessary to collect grab samples and then determine TSS in the laboratory. One of the less expensive and more efficient methods utilized to predict TSS is the turbidity. Turbidity measurements have been utilized in diverse environments. Patil et al. (2011) developed a linear regression model to predict TSS from turbidity measurements for each primary particle class. Packman (1999) developed a model to determine TSS from turbidity measurements in urbanized streams in the Puget Lowlands. Data collected from nine streams with both urbanized and rural drainage areas showed a strong log-linear relationship between turbidity and TSS. However, turbidity is also affected by many other parameters other than particle concentration. Water color may be affected by dissolved solids and temperature (Malcolm, 1985), as well as the shape, size, and mineral composition of particles (Clifford et al. 1995; Gippel, 1988), all of which can significantly affect turbidity readings.

The purpose of this section was to develop a simple regression model to evaluate whether turbidity could also be used to accurately estimate the total solid measurements for the ditch check and erosion control blanket studies. All ditch check data is plotted in Figure 5.28 with a semi-logarithmic regression model, while data collected from the erosion control blanket evaluation (except for the control plot) with a simple linear regression is presented in Figure 5.29. The turbidity measurements obtained from the erosion control plot were discarded, because they were out of the range of the turbidity meter calibration; hence, including those results could lead to misinterpretation. The semi-logarithmic model seems to be a more convenient model for broader ranges of data. Different particle sizes along with other water properties can influence the linear relationship between the NTU and TSC, and being only valid for a smaller range of the data.

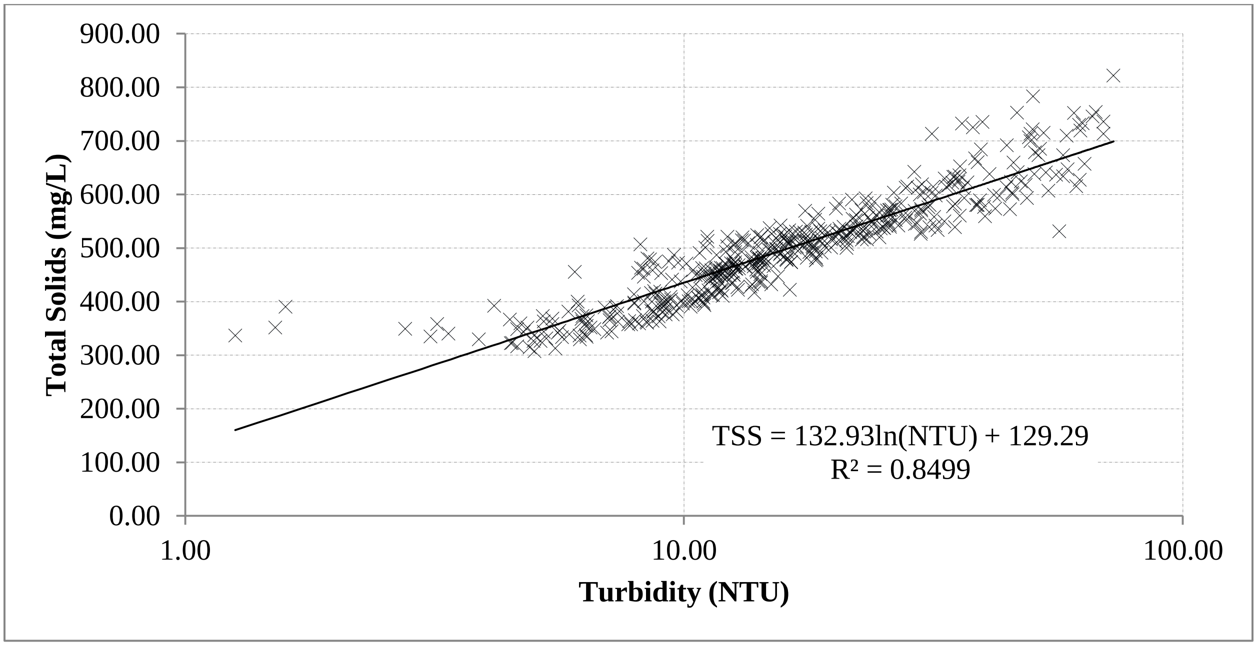


Figure 5.28. Total solids and turbidity data for ditch checks with semi-logarithmic regression model.

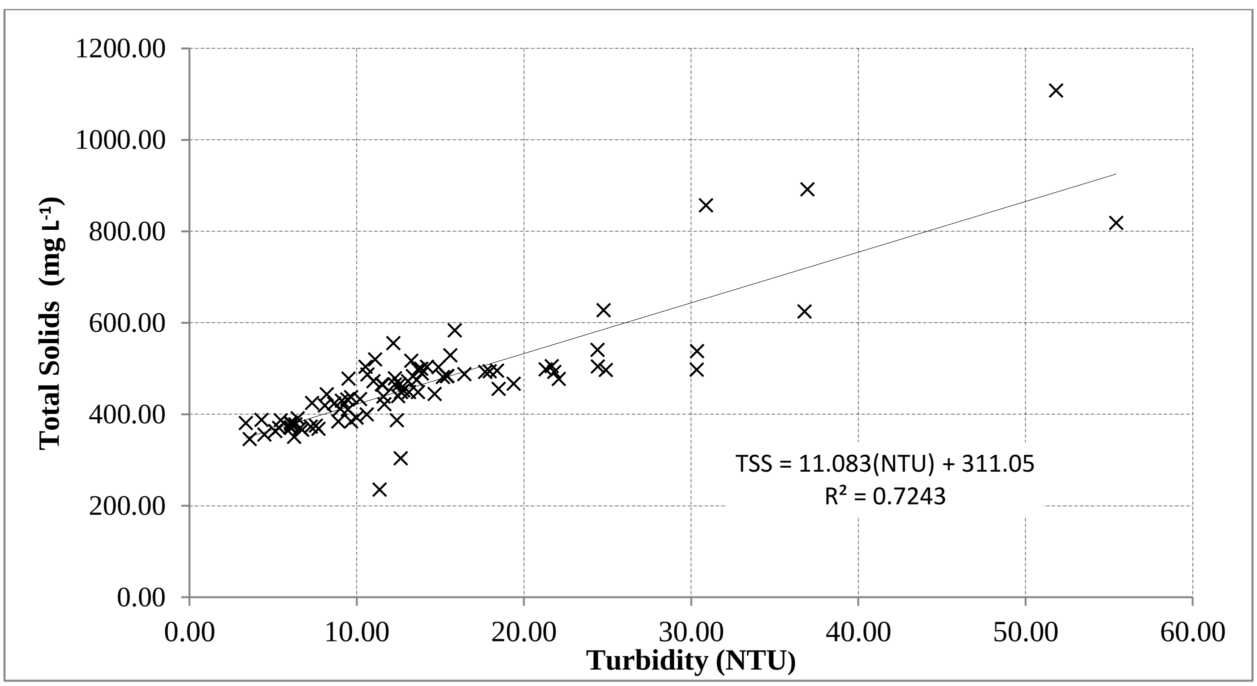


Figure 5.29. Total solids and turbidity data for erosion control blankets with linear regression model.

The model for both ditch check and erosion control blanket evaluation data showed strong relationships between turbidity and TSC, with R^2 values of 0.85 and 0.72, respectively. These results indicated that turbidity readings could be useful in estimating the total solids of samples collected in the field before analyzing them in the laboratory.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

Field scale evaluation protocols for ditch checks and erosion control blankets were successfully developed at the ESCRTC at the University of Illinois at Urbana-Champaign. These evaluation protocols were developed based on current studies and were designed to be reliable, easily replicable in similar testing facilities elsewhere, and to ameliorate any adverse weather effects.

The ditch check testing protocol was successfully implemented, and three different products were evaluated under three flow conditions. Based on observations made during the study, recommendations were developed to improve the testing protocol for future product evaluation.

In order to quantify the total sediment retained by the ditch check products, laser scanning was performed for both ditch checks prior to testing and after every test replication. This scan covered an area measuring 2 m upstream of each product and along the entire width of the wetted channel portion. For analyzing the total volume of sediment retained, only the downstream ditch check was used. The total volume of sediment was also computed for the upstream ditch check, but was left out of the analysis because the scour created by cascading at the weir was highly dependent on the product characteristics, which made comparison among the products more difficult.

As described in the testing protocol, channel scans were performed before testing and after each replication. This task efficiency could be improved by only performing the scans before evaluation and after the third replication, so that the total volume of sediment could be used to estimate the soil disturbance in the channel bed. The surface scans only provided information about the sediment being retained, but did not permit a complete mass balance analysis to quantify the total sediment loss in the channel. A complete scan of the area between the two installed ditch checks was not feasible at the time of testing, but the equipment software has been upgraded so that such an operation can now be easily performed. Therefore, scanning the area between the upstream and downstream ditch checks before testing and after the third replication will permit accurate estimation of both the total soil loss and soil disturbance in the channel bed.

The ditch check products were evaluated under different flow rate conditions for fixed soil type and channel slope conditions. It is recommended that future studies also test the products under different soil types and slope conditions that are commonly found in construction sites.

The evaluation protocol for erosion control blankets was developed to perform product testing under controlled conditions. A wind screen was installed surrounding the erosion plots to minimize the impact of wind on simulated rainfall distribution within the erosion plots. The erosion control blankets were wetted after installation and prior to testing to produce the same soil moisture conditions when testing different products. This pre-wetting task took up to three hours per plot depending on the product and soil conditions; however, due to the extremely dry summer the soil saturation was not replicable for all products tested, and the total runoff obtained was significantly affected. It is therefore recommended that future studies perform the soil pre-wetting operation after product installation and before testing for a fixed period of time so that the soil saturation is replicable, and testing should not be performed when the weather conditions can affect this operation.

Even though these desirable testing conditions were not present during erosion control blanket evaluation, the results still indicated that the products were an effective best management practice to control the erosion on hillside slopes as compared to the control plot. Another factor that should be considered for future studies is the droplet size generated by the rainfall simulator. It was observed during testing that the simulated rainfall was very fine, which prevented most rainwater splash erosion and left surface runoff as the main mechanism of erosion.

The soil type, rainfall duration, and rainfall rate were constant for the erosion control blanket evaluations, which produced results that were comparable only under those particular conditions. It is highly recommended that future studies evaluate the erosion control blankets under different soil type and rainfall conditions that are also found in the area of interest.

Additional product evaluations and testing protocols are under development for future studies at the ESCRTC as well. This study also provided guidance to the Illinois Department of Transportation (IDOT) in the installation and maintenance of sediment control and erosion control products. These protocols will continue to provide reliable product performance data to help IDOT select and modify approved erosion and sediment control products for Illinois construction sites.

REFERENCES

American Excelsior Company. 2012. Curlex I installation guide. Dallas, Texas: American Excelsior Company. Avalilable at: americanexcelsior.com. Accessed 15 May 2012.

American Excelsior Company. 2012. Sediment Log installation guide. Dallas, Texas: American Excelsior Company. Avalilable at: americanexcelsior.com. Accessed 1 May 2012.

American Excelsior Company. 2012. Curlex I installation guide. Dallas, Texas: American Excelsior Company. Avalilable at: americanexcelsior.com. Accessed 15 May 2012.

ASTM. 1985d. Standard Test Method for Particle-Size Analysis of Soils. D-422-63. American Society of Testing and Materials, West Conshohocken, PA.

ASTM. 2010. Standard Test Method for Determination of Temporary Ditch Check Performance in Protecting Earthen Channels from Stormwater-Induced Erosion. D-7208-06. American Society of Testing and Materials, West Conshohocken, PA.

ASTM. 2007a. Standard Test Method for Determination of Rolled Erosion Control Product (RECP) Performance in Protecting Hillslopes from Rainfall-Induced Erosion. D-6459-07. American Society of Testing and Materials, West Conshohocken, PA.

ASTM. 2007b. Standard Test Methods for Determining Sediment Concentration in Water Samples. D-3977-97. American Society of Testing and Materials, West Conshohocken, PA.

Beighley, R. E., B. Scholl, L. B. Faucette, and J. Governo. 2010. Runoff characteristics for construction site erosion control practices. *Journal of Irrigation and Drainage Engineering* 136(6): 405-413.

Benik, S. R., B. N. Wilson, D. D. Biesboer, B. Hansen, and D. Stenlund. 2003a. Evaluation of erosion control products using natural rainfall events. *Journal of Soil and Water Conservation* 58(2): 98-105.

Benik, S. R., B. N. Wilson, D. D. Biesboer, B. Hansen and D. Stenlund. 2003b. Performance of erosion control products on a highway embankment. *Transactions of the American Society of Agricultural Engineers* 46(4): 1113-1119.

Clifford, N.J., Richards, K.S., Brown, R.A. and Lane, S.N. 1995. Laboratory and Field Assessment of an Infrared Turbidity Probe and Its Response to Particle Size and Variation in Suspended Sediment Concentration. *Hydrological Sciences.* 40(6): 771-791.

Day, P. R. 1965. Particle Fractioning and Particle-Size Analysis p .545-567. In C.A. Black et al (ed.) Methods of soil analysis, Part1. Agronomy 9: 545-567

Endres, T. J. 2003. Soil survey of Champaign County, Illinois. *Ill. Agri.Exp Stat.Soil Rep.174*.

EPA. Stormwater Phase I final rule: National Pollutant Discharge Elimination (NPDES). 803-F-00-001. Fact Sheet 1.0. 2000. Environmental Protection Agency.

EPA. Stormwater Phase II final rule: Construction site runoff control minimum control measure. 833-F-00-008, Fact Sheet. 2000. Environmental Protection Agency.

Faucette, L. B., B. Scholl, R. E. Beighley, and J. Governo. 2009. Large-scale performance and design for construction activity erosion control best management practices. *Journal of Environmental Quality* 38(3): 1248-1254.

Gee, G.W., Baude, J.W. 1986. *Methods of Soil Analysis.* Madison, Wisconsin: Amer. Soc. of Agron., Inc., Soil Sci. Soc. of Amer.

Gippel, C.J. 1995. Potential of Turbidity Monitoring for Measuring the Transport of Suspended Solids in Streams. *Hydrological Processes.* 9: 83-97.

Godfrey, S. H. and M. K. Curry. 1995. TTI hydraulics and erosion control laboratory research field performance of erosion-control blankets. *Landscape and Urban Planning* 32(3): 161-167.

Hollander, Myles and Wolfe, Douglas A. 1973. *Nonparametric Statistical Methods.* New York: John Wiley & Sons.

IEPA. General NPDES Permit for Stormwater Discharges from Construction Site Activities. NPDES Permit No. ILR10. 2008. Illinois Environmental Protection Agency.

Landphair, H.C., McFalls, J.A., and Li, M., 1997. Alternatives to Silt Fence for Temporary Sediment Control at Highway Construction Sites. TxDOT 1737-S.

Malcolm, R.L. 1985. Geochemistry of Stream Fulvic and Humic Substances. In: Humic Substances in Soil, Sediment, and Water. New York: Aiken, G.R., et.al. John Wiley and Sons, Inc., MacFalls, Jett., Li, Ming-Han., Raut Desai, Aditya B. 2010. Roadside Sediment Control Device Evaluation Program: Technical Report. *Report 0-5948-1.*, Austin, Texas.

Monical, Joseph W. 2011. Development of a research and demonstration facility for the evaluation of stormwater runoff, erosion control, and sediment control best management practices. Master Thesis. Urbana, Il: University of Illinois at Urbana-Champaign, Department of Agricultural and Biological Engineering.

Morgan, R. P. C. 1995. *Soil erosion and conservation.* Harlow, Essex, England: Longman

Nilex. 2012. GeoRidge installation guide. Denver, CO: Nilex Inc. Available at: www.nilex.com. Accessed 1 May 2012.

Owens, David W., Jopke Peter., Hall, David W., Balousek, Jeremy., Roa, Aicardo . *Soil Erosion from two Small Construction Sites, Dane County, Wisconsin.* U.S. Geological Survey. Available at: http://wi.water.usgs.gov/pubs/fs-109-00/fs-109-00.pdf. Accessed 12 December 2012

Packman, James J., Comings, Karen J., Booth, Derek B. 1999. Using turbidity to determine total suspended solids in urbanizing streams in the Puget Lowlands. College of Forest Resources, University of Washington. Seattle, WA.

Patil, S. S., Barfield, B.J., Wilber, G.G. 2011. Turbidity modeling based on the concentration of total suspended solids for stormwater runoff from construction and development sites. *World Environmental and Water Resources Congress 2011: Bearing Knowledge for Sustainability - Proceedings of the 2011 World Environmental and Water Resources Congress,* p 477-486, 2011, *World Environmental and Water Resources Congress 2011: Bearing Knowledge for Sustainability - Proceedings of the 2011 World Environmental and Water Resources Congress*

Pitt, Robert., Clark, Shirley E., Lake, Donald. 2007. *Construction Site Erosion and Sediment Controls: Planing, Desing and Performance.* Lancaster, Pennsylvania; DEStech Publications, Inc.

Smajstrla, Allen G., Harrison, Dalton S. 1981. Weirs for open-channel flow measurement. Agricultural and Biological Engineering Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Gainesville, Florida.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available at: http://websoilsurvey.nrcs.usda.gov/. Accessed 26 February 2011.

Terrence J. Toy, George R. Foster, Kenneth G. Renard. 2002. *Soil erosion: processes, prediction, measurement, and control*. New York : J. Wiley

Theisen, Marc S., Spittle, Kevin. 2006. *A Quantitative Comparison of Sediment Retention Devices under Standardized Test Conditions.*Profile Products, LLC. Ankeny, Iowa.

Triangular Silt Dike Company. 2012. Triangular Silt Dike installation guide. Luther, OK: Triangular Silt Dike Company. Available at: ww.tri-siltdike.com. Accessed 1 May 2012.

Wolfe, Kevin B., Peters, Janette L. *Qualitative Valuation of Perfomrnace Testing for Sediment Retention Devices (SRDS).* Civil & Environmental Consultants, Inc. Frsnklin, Tennessee.

Welch, B.L. 1947. The generalization of 'Student's' problem when several different population variances are involved. *Biometrika* 34(1/2): 28-35.

Wright, Kevin N. 2010. Evaluation of check dams for sediment control on disturbed land surfaces. Master Thesis. Urbana, Il: University of Illinois at Urbana-Champaign, Department of Agricultural and Biological Engineering.

APPENDIX A

TSC FOR ALL DITCH CHECK EVALUATIONS

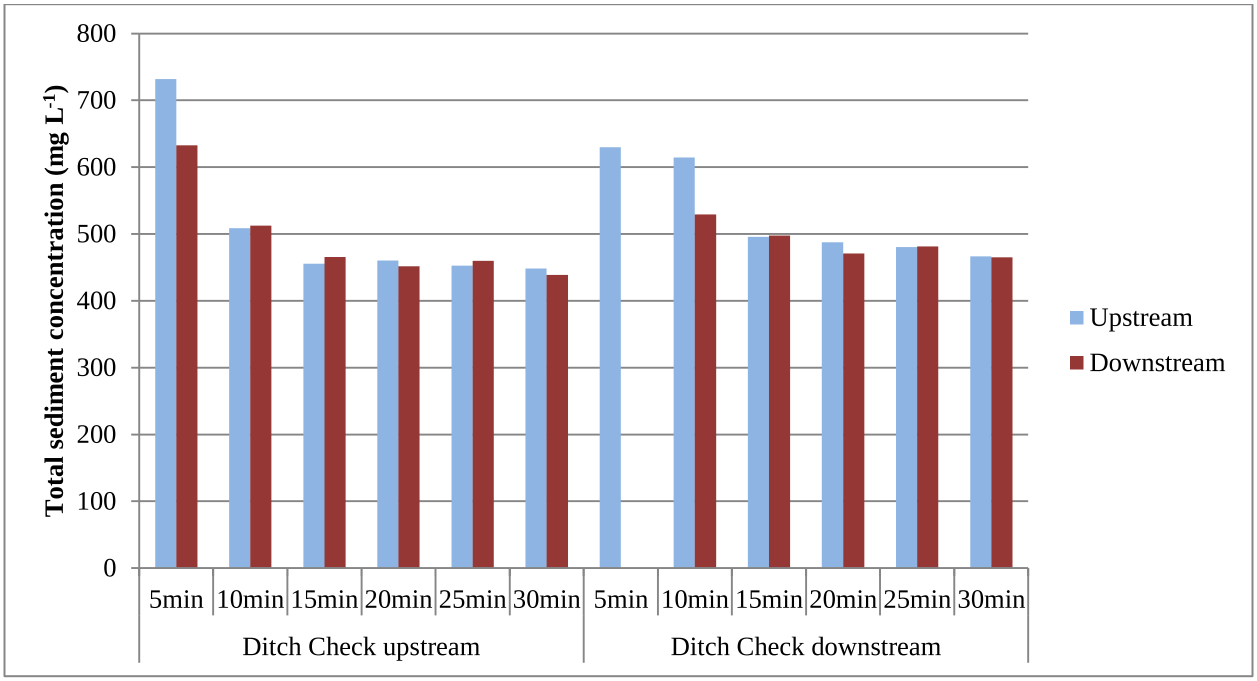


Figure A.1. Replication 1 TSC values for Triangular Silt Dike under 10 L s^{-1} flow rate.

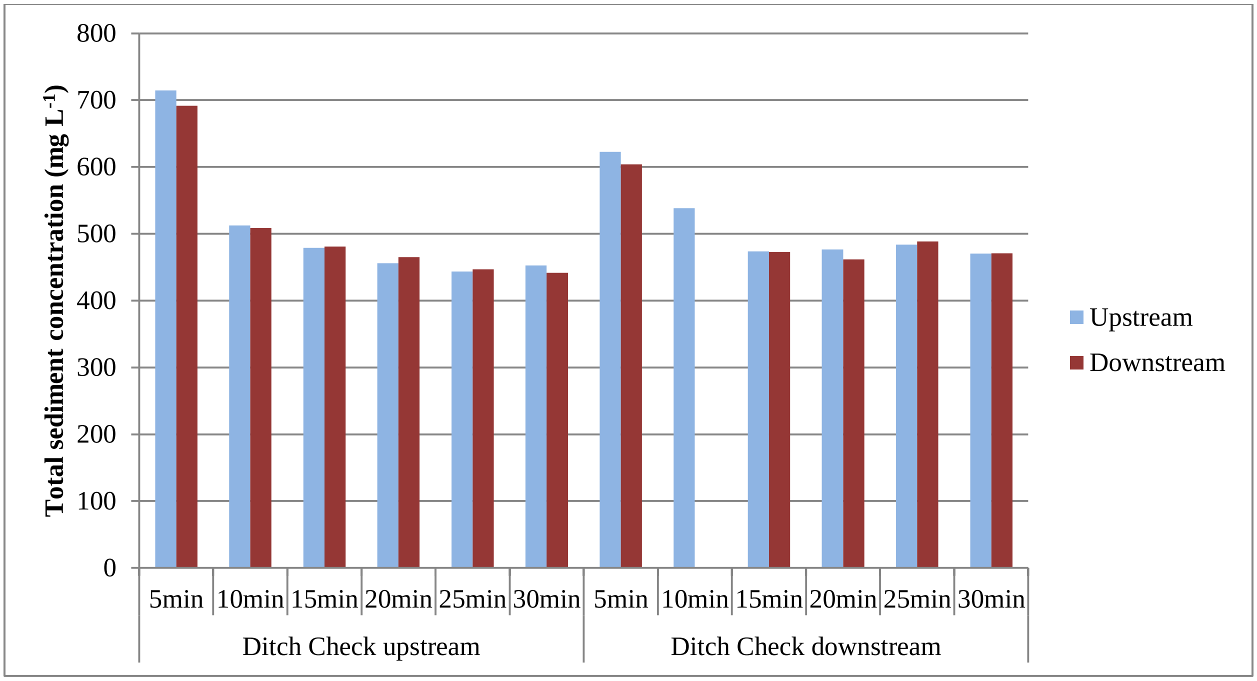


Figure A.2. Replication 2 TSC values for Triangular Silt Dike under 10 L s^{-1} flow rate.

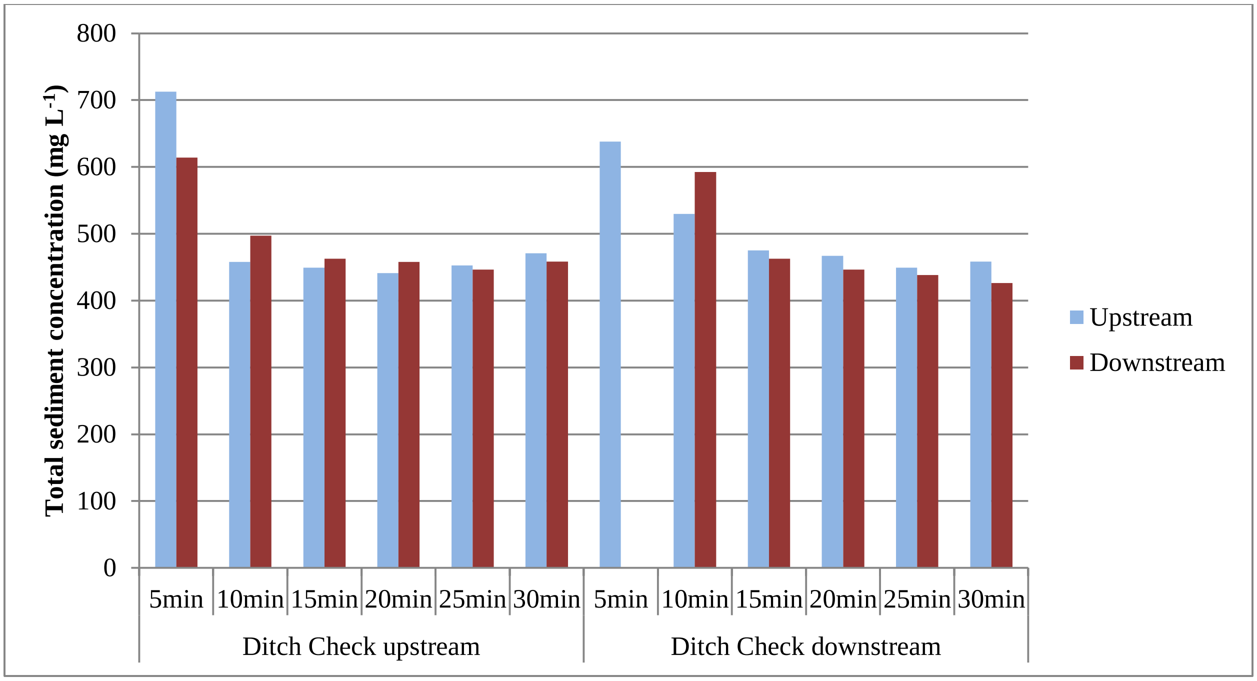


Figure A.3. Replication 3 TSC values for Triangular Silt Dike under 10 L s^{-1} flow rate.

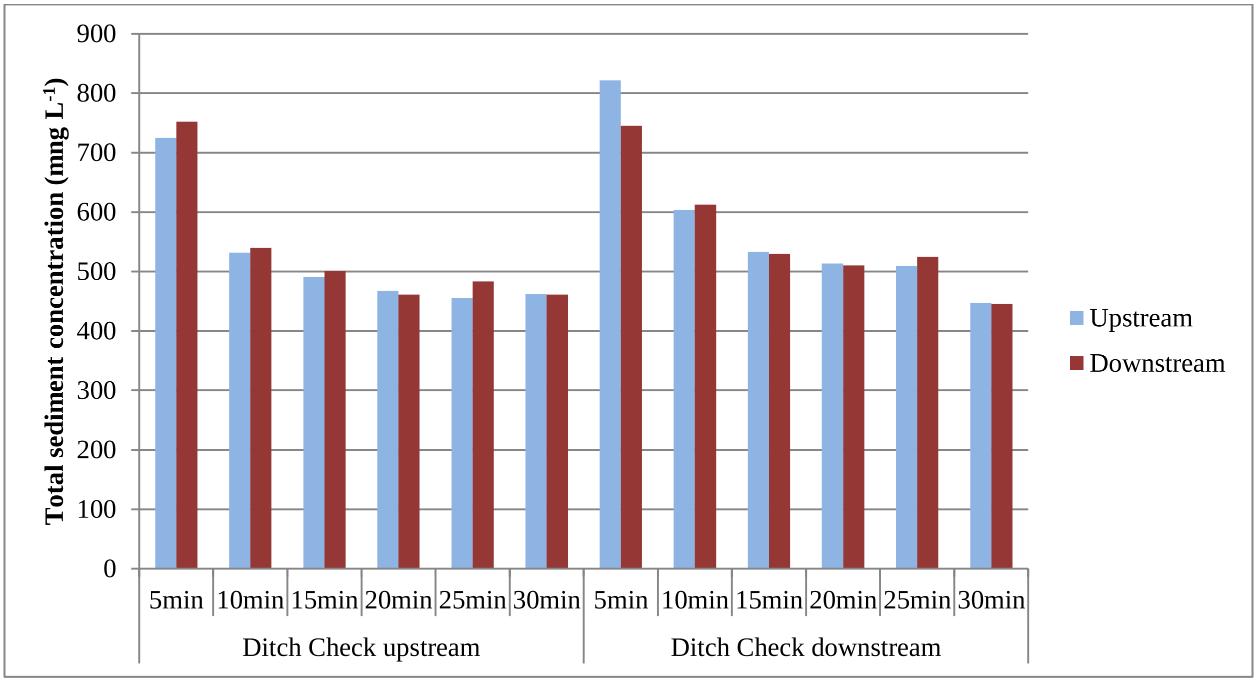


Figure A.4. Replication 1 TSC values for GeoRidge under 10 L s^{-1} flow rate.

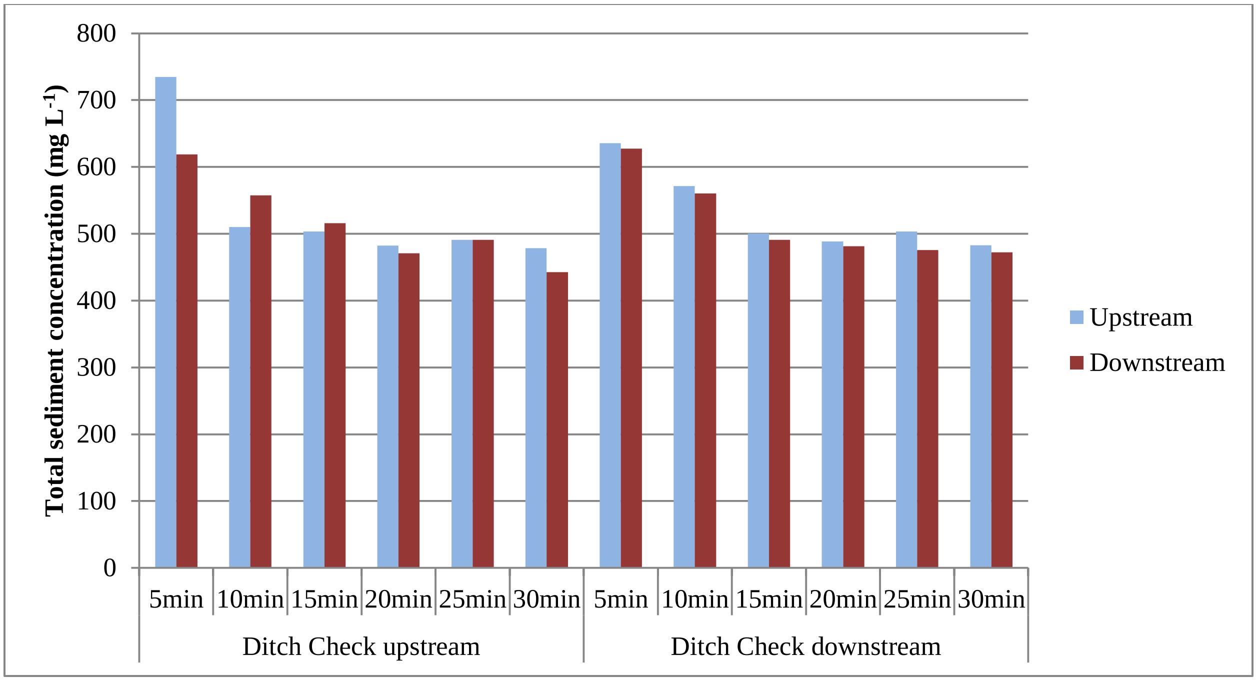


Figure A.5. Replication 2 TSC values for GeoRidge under 10 L s^{-1} flow rate.

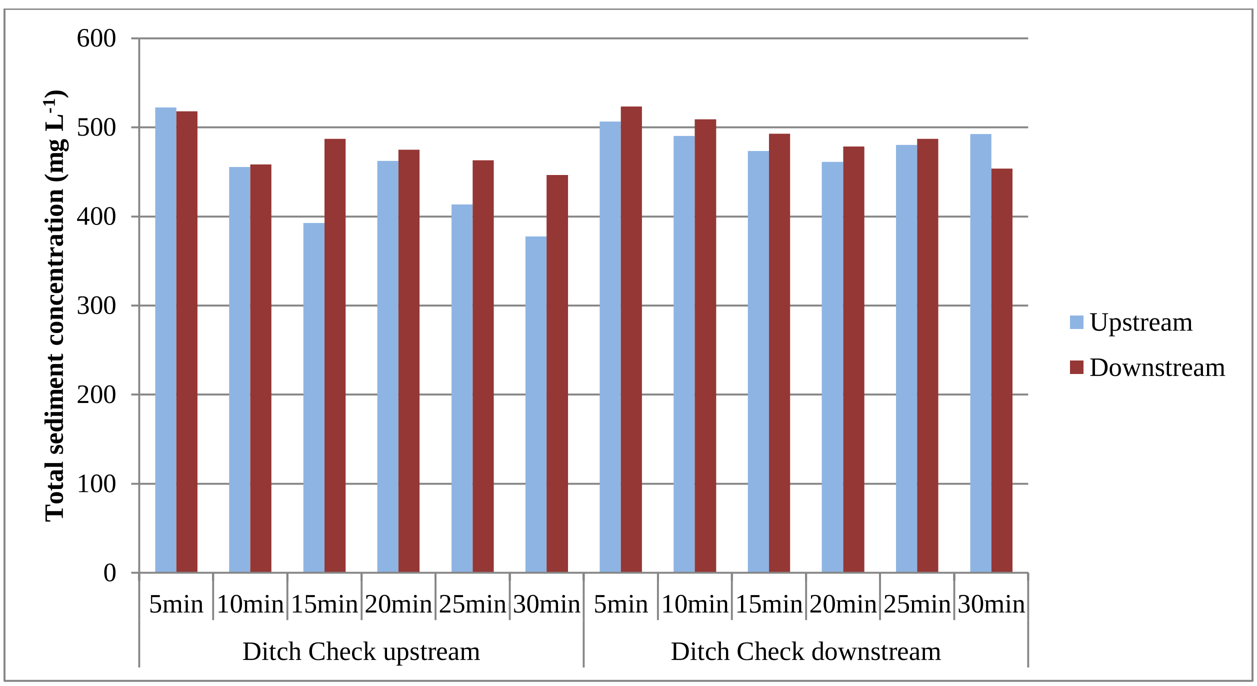


Figure A.6. Replication 3 TSC values for GeoRidge under 10 L s^{-1} flow rate.

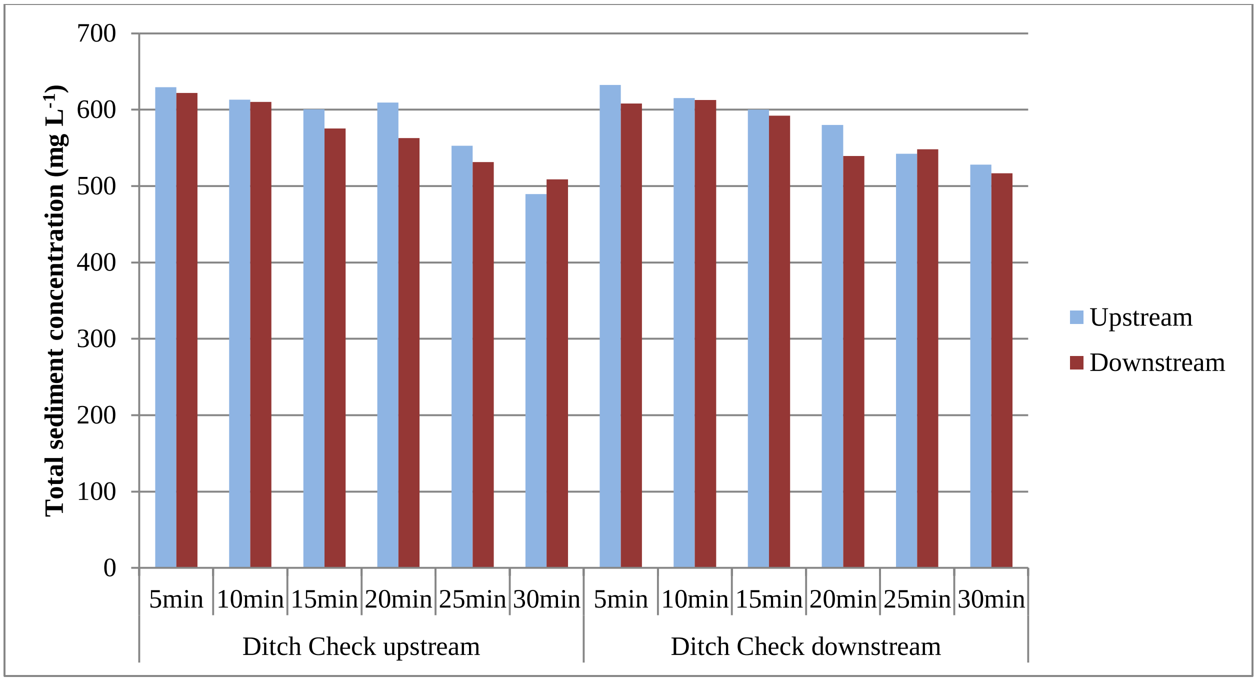


Figure A.7. Replication 1 TSC values for Sediment Log under 10 L s^{-1} flow rate.

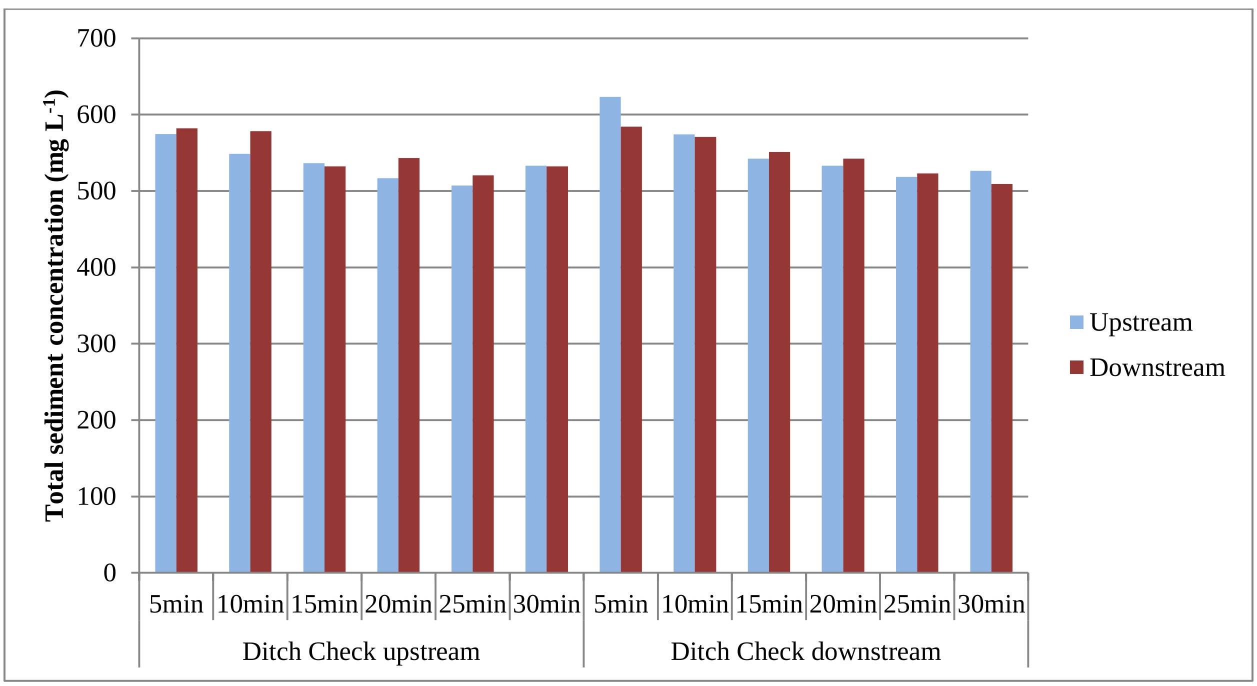


Figure A.8. Replication 1 TSC values for Sediment Log under 10 L s^{-1} flow rate.

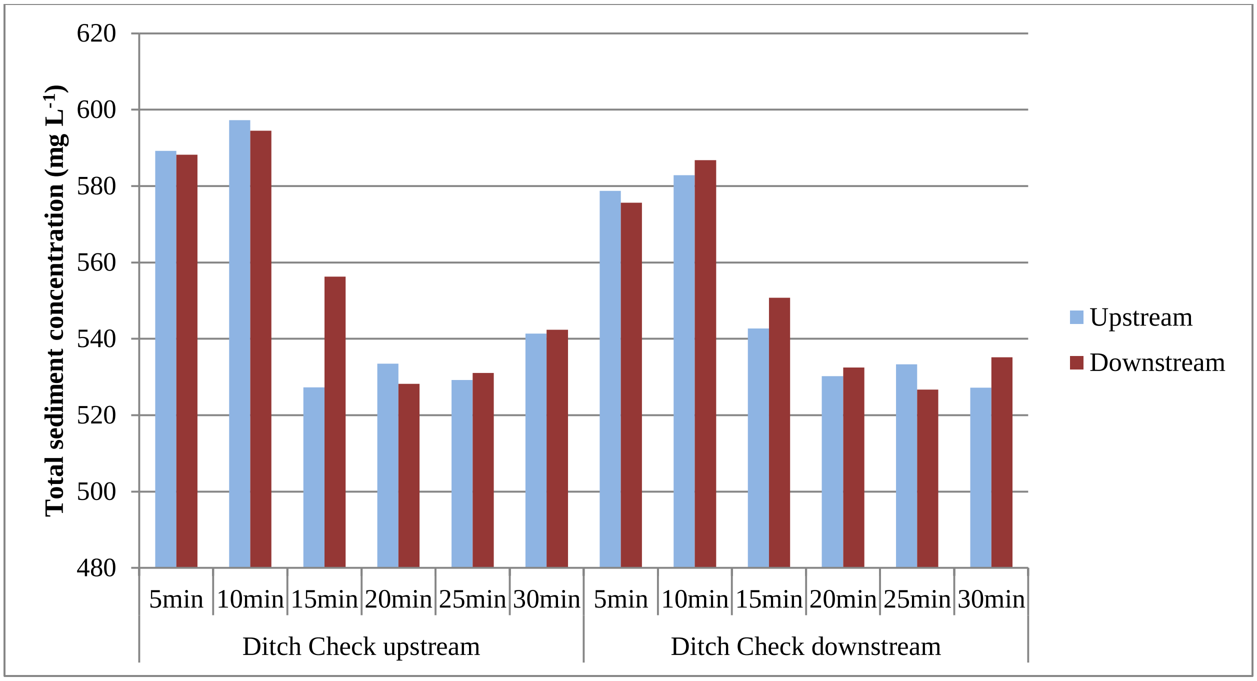


Figure A.9. Replication 1 TSC values for Sediment Log under 10 L s^{-1} flow rate.

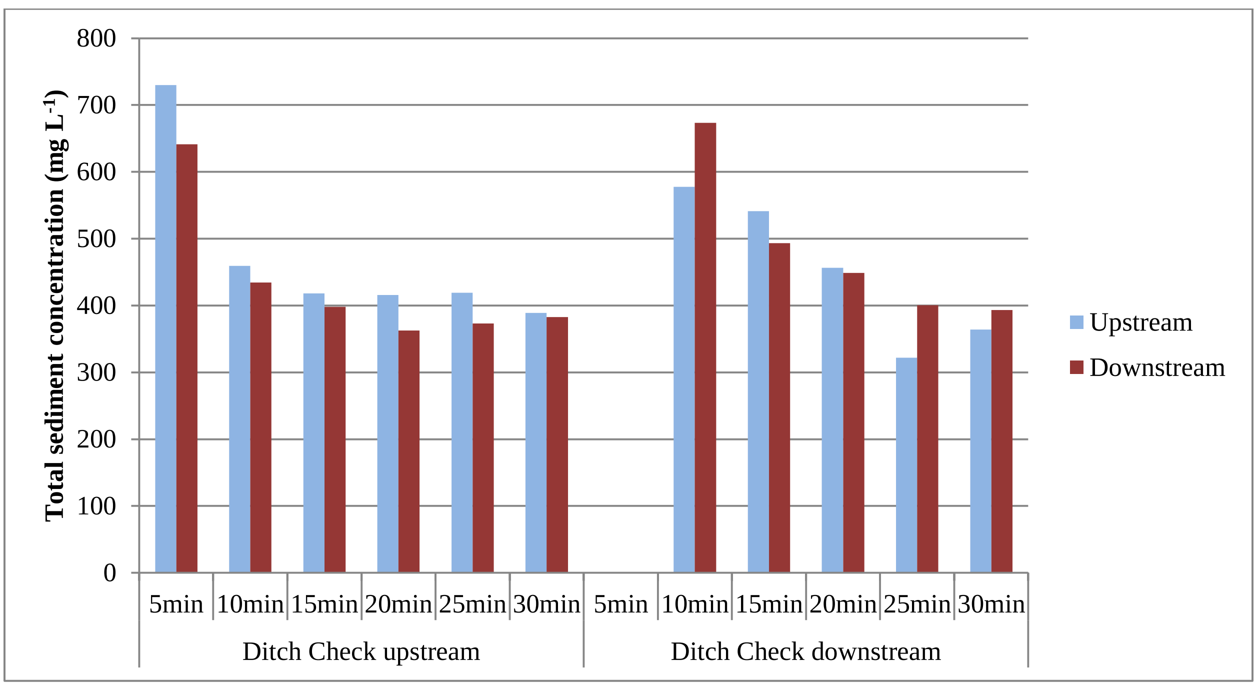


Figure A.10. Replication 1 TSC values for Triangular Silt Dike under 7.5 L s^{-1} flow rate.

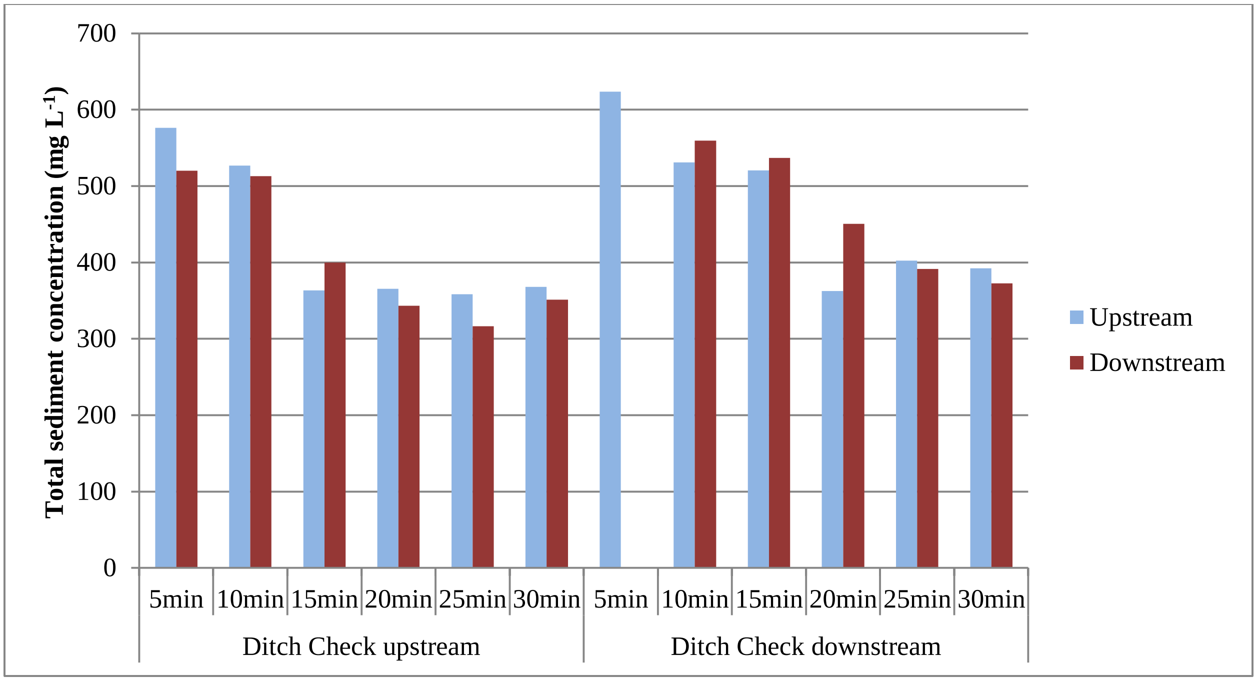


Figure A.11. Replication 1 TSC values for Triangular Silt Dike under 7.5 L s^{-1} flow rate.

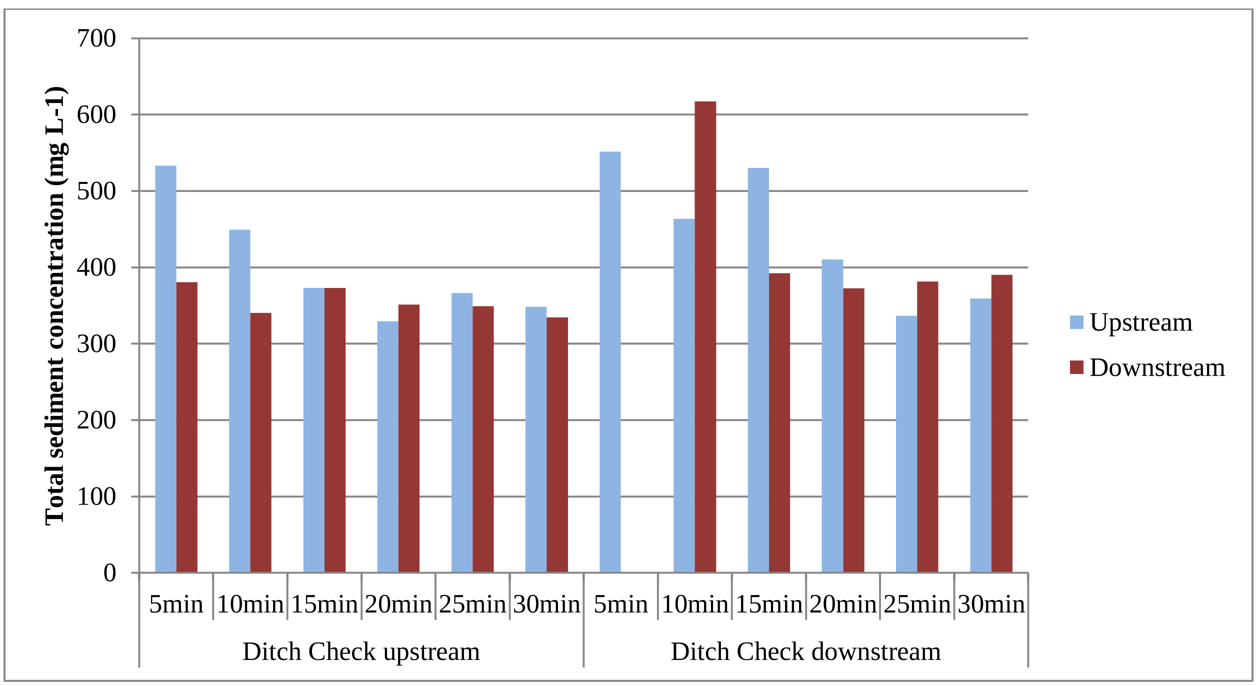


Figure A.12. Replication 1 TSC values for Triangular Silt Dike under 7.5 L s^{-1} flow rate.

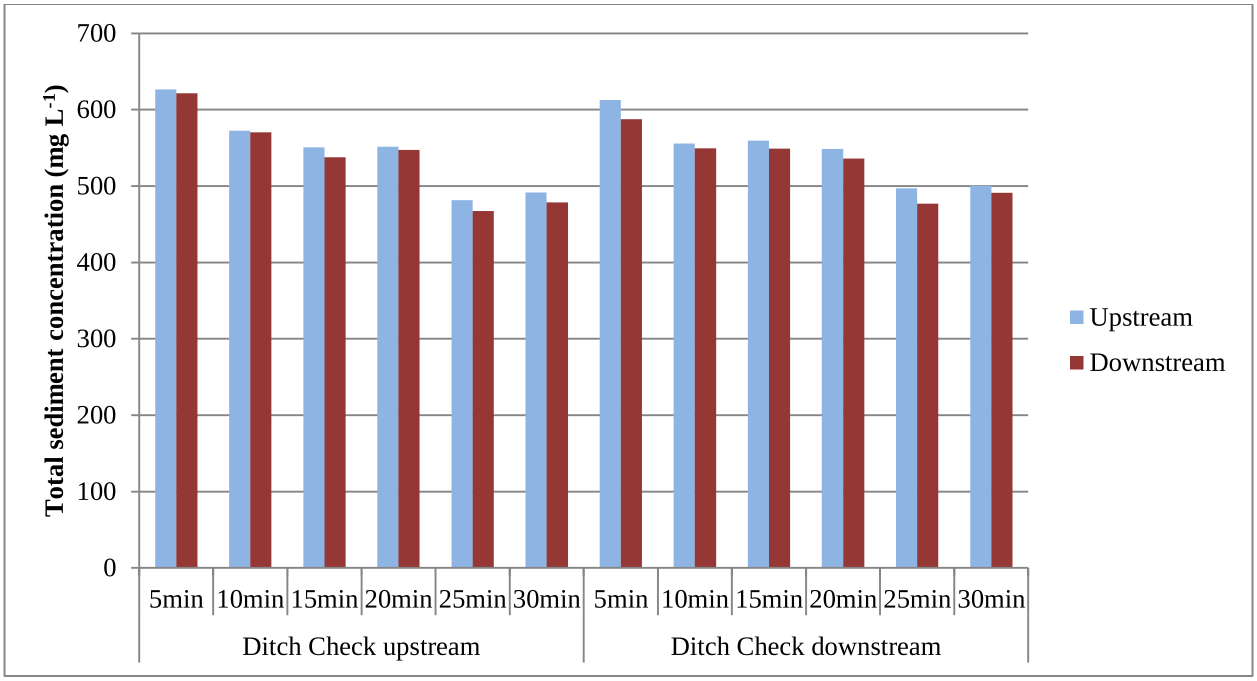


Figure A.13. Replication 1 TSC values for GeoRidge under 7.5 L s^{-1} flow rate.

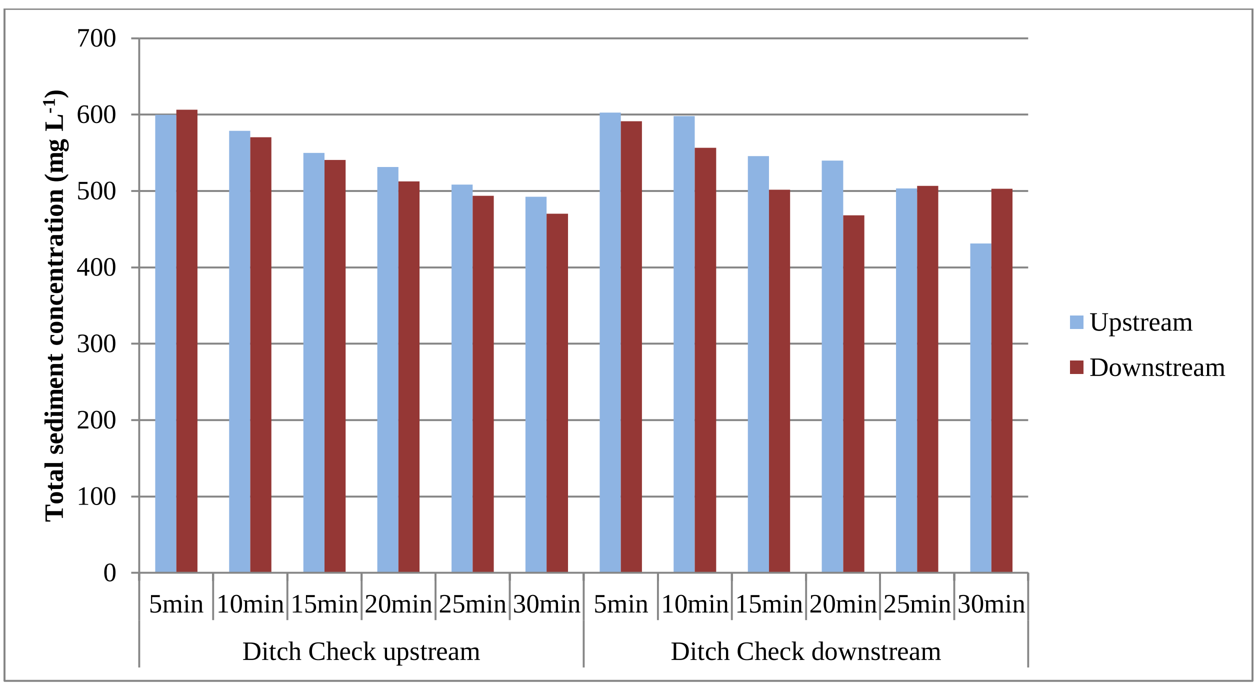


Figure A.14. Replication 2 TSC values for GeoRidge under 7.5 L s^{-1} flow rate.

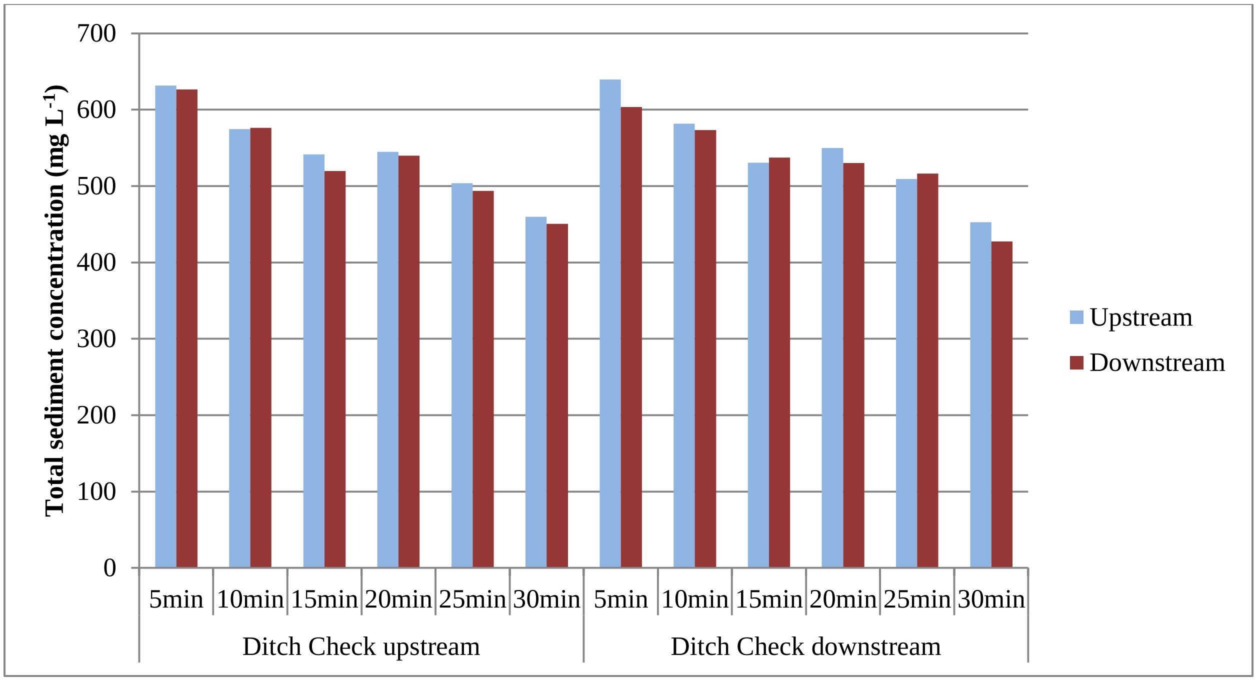


Figure A.15. Replication 3 TSC values for GeoRidge under 7.5 L s^{-1} flow rate.

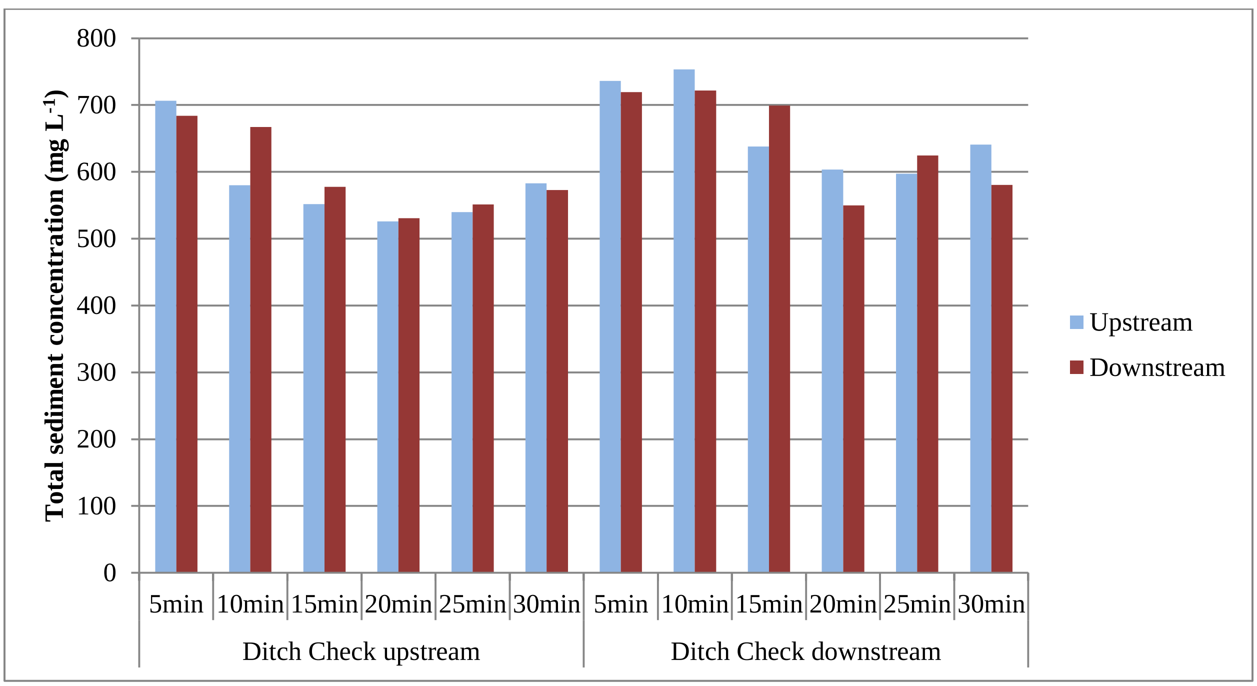


Figure A.16. Replication 1 TSC values for Sediment Log under 7.5 L s^{-1} flow rate.

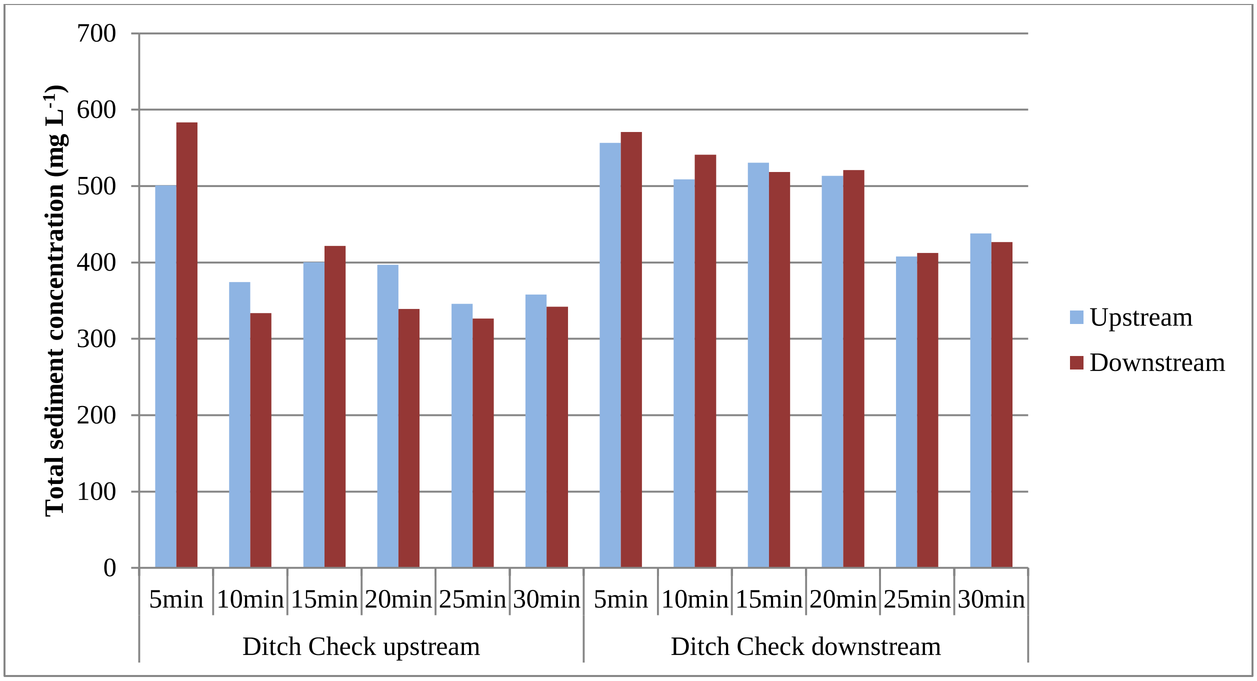


Figure A.17. Replication 2 TSC values for Sediment Log under 7.5 L s^{-1} flow rate.

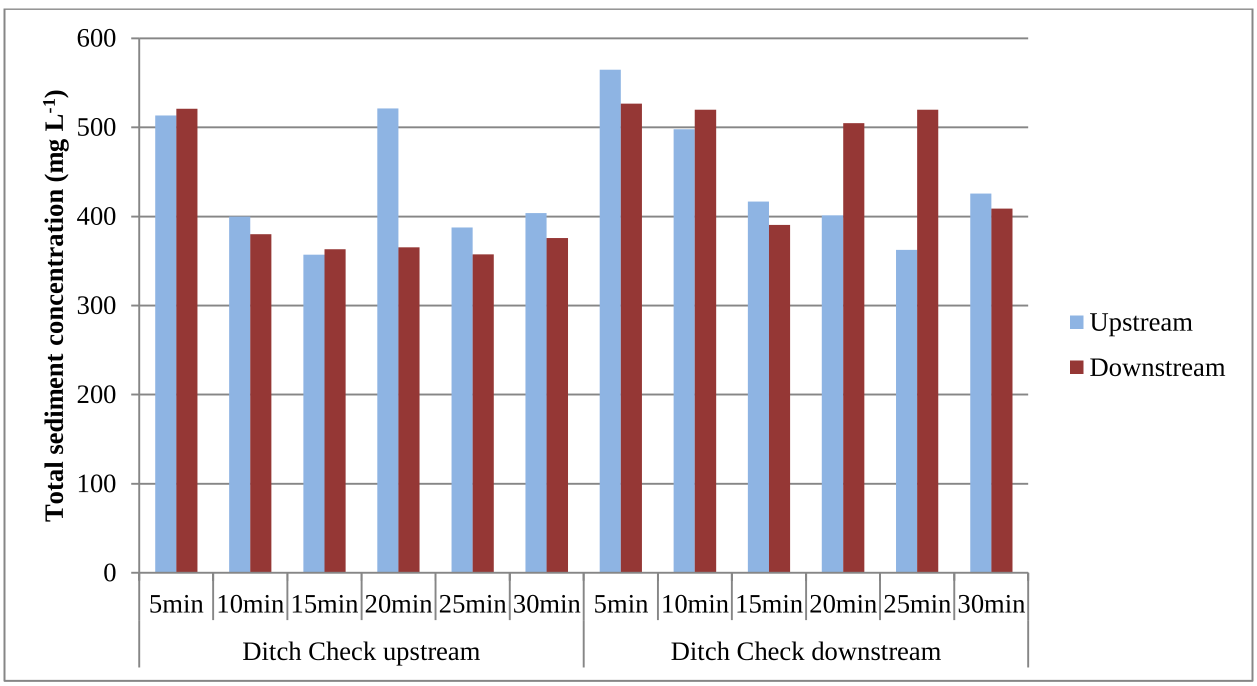


Figure A.18. Replication 3 TSC values for Sediment Log under 7.5 L s^{-1} flow rate.

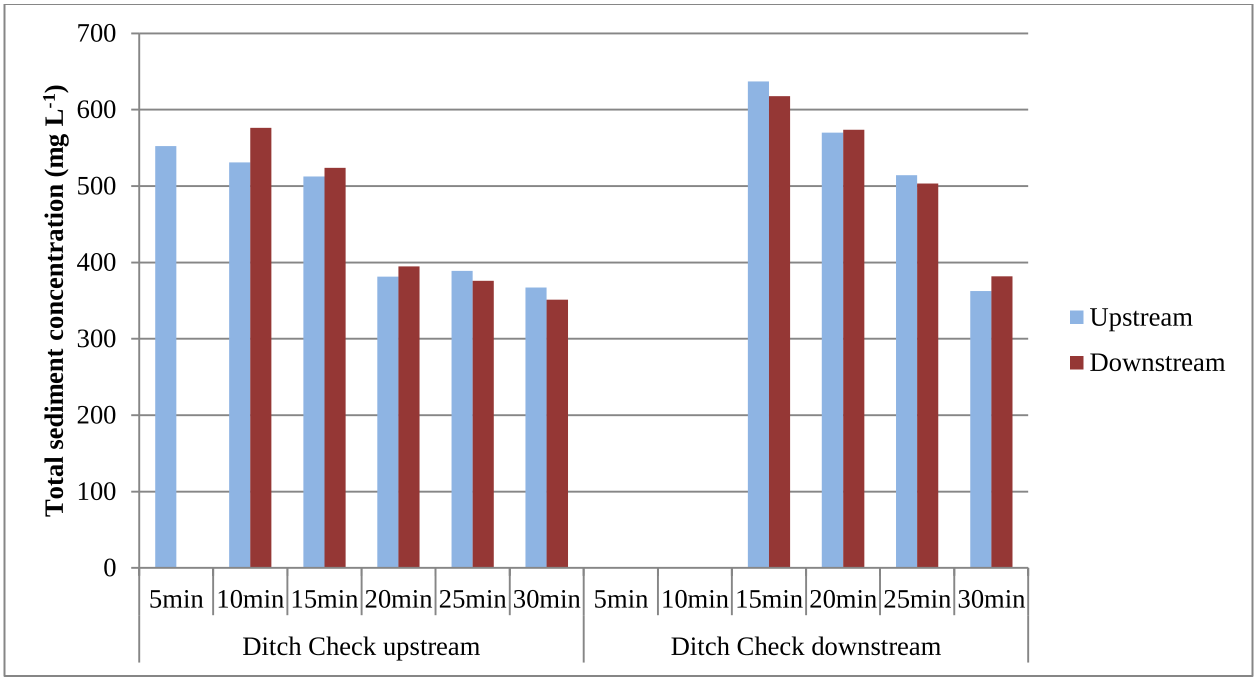


Figure A.19. Replication 1 TSC values for Triangular Silt Dike under 5 L s^{-1} flow rate.

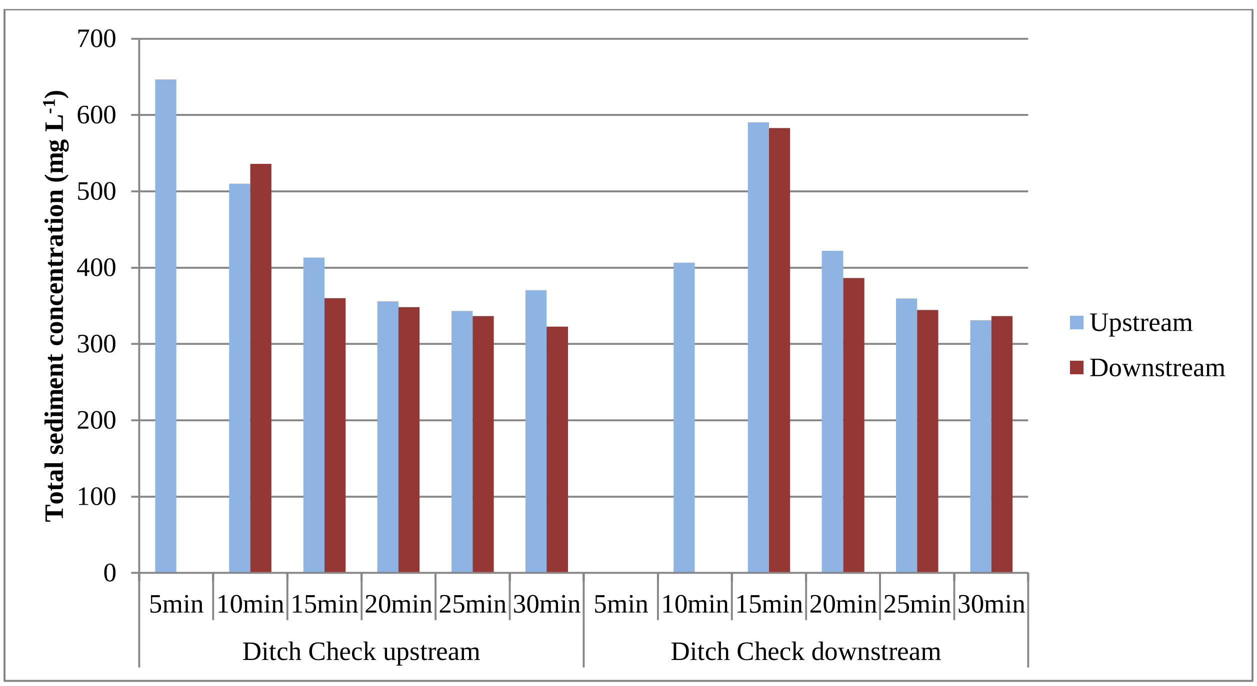
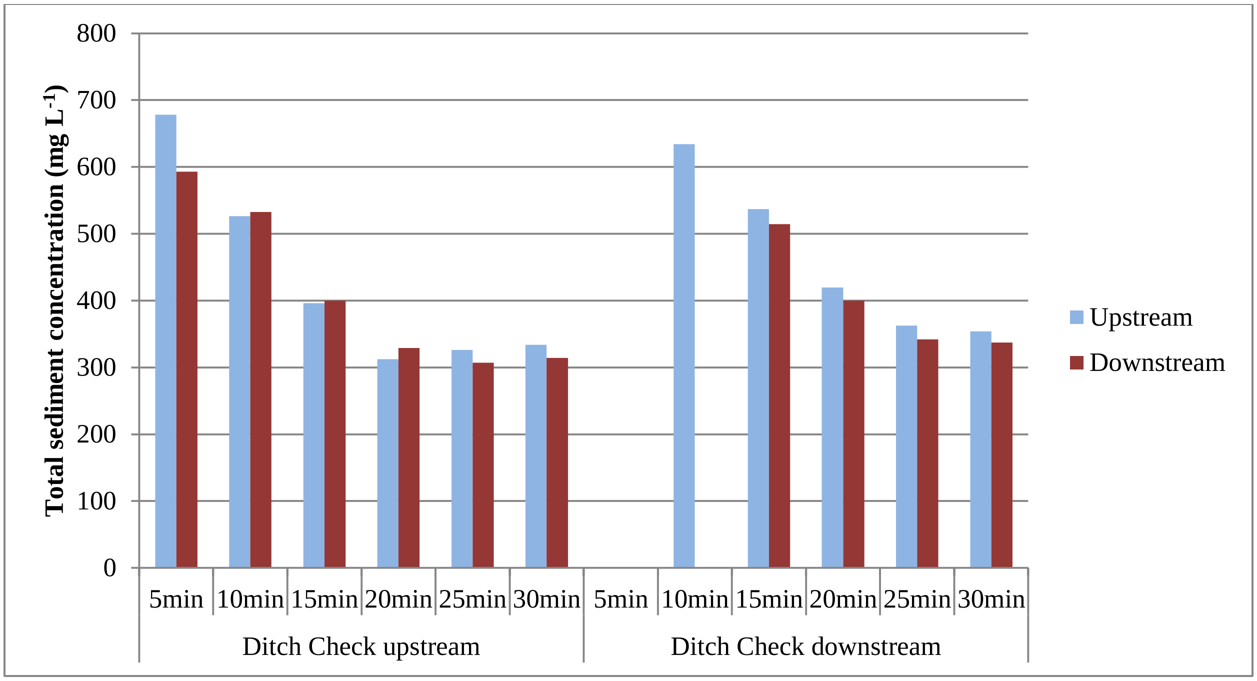


Figure A.20. Replication 2 TSC values for Triangular Silt Dike under 5 L s^{-1} flow rate.



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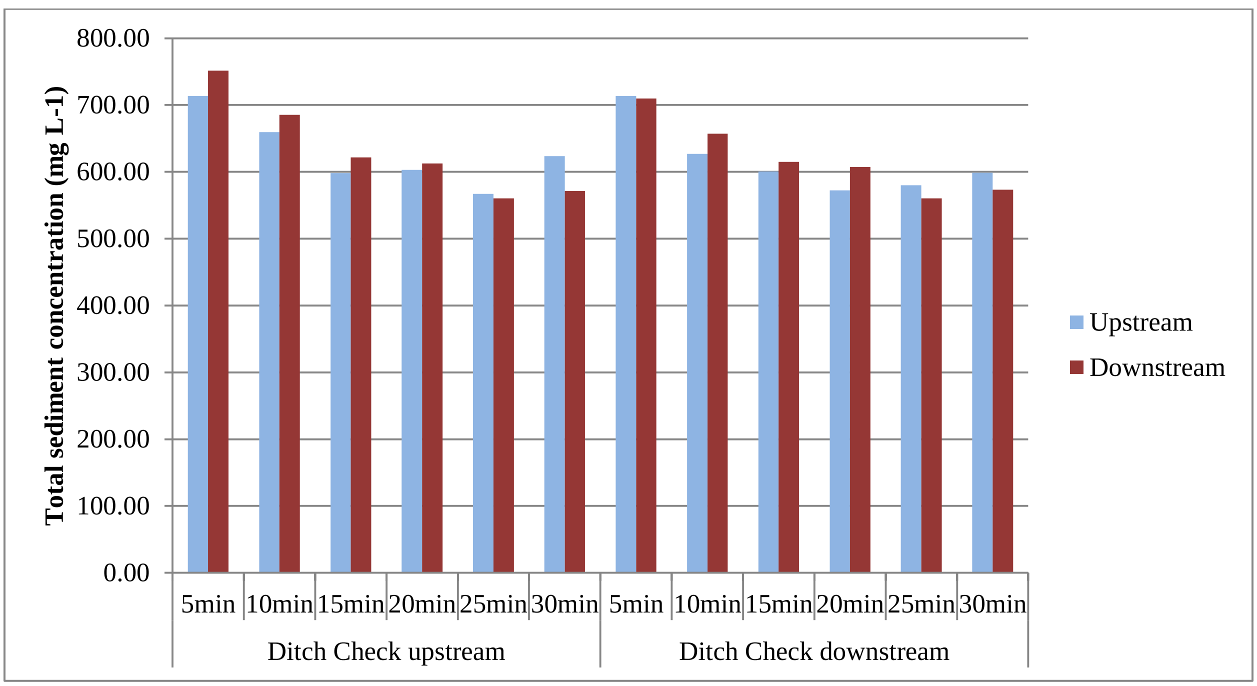


Figure A.22. Replication 1 TSC values for GeoRidge under 5 L s^{-1} flow rate.

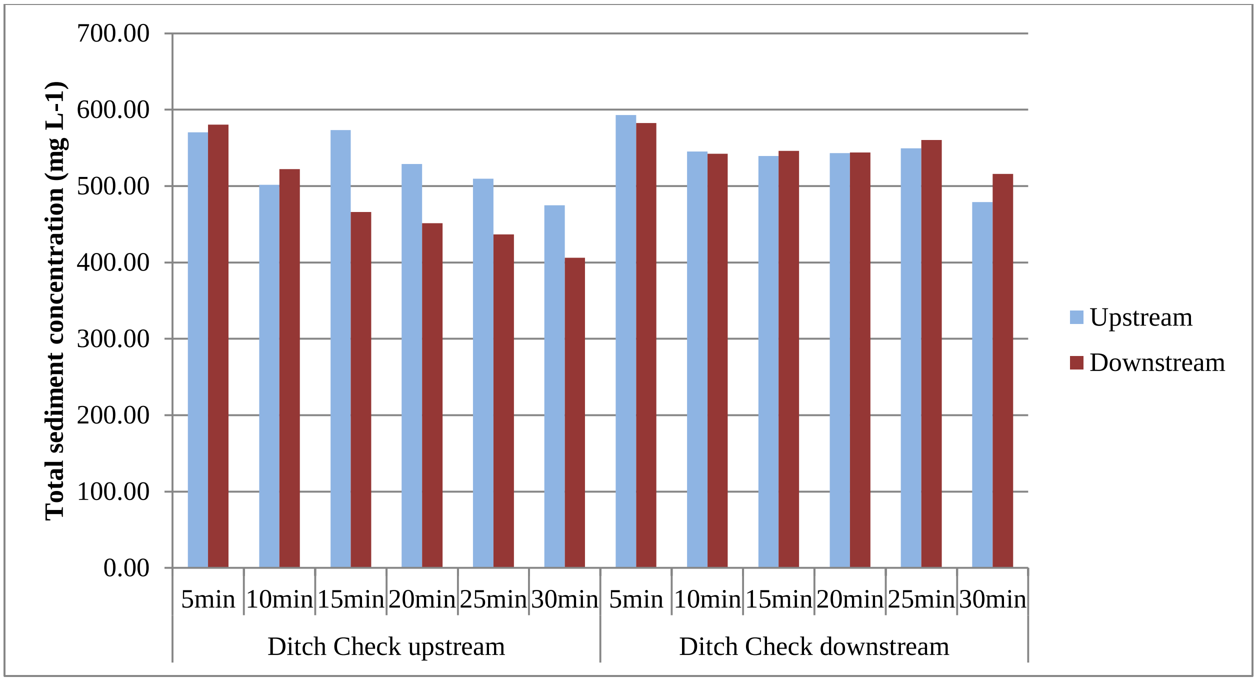


Figure A.23. Replication 2 TSC values for GeoRidge under 5 L s^{-1} flow rate.

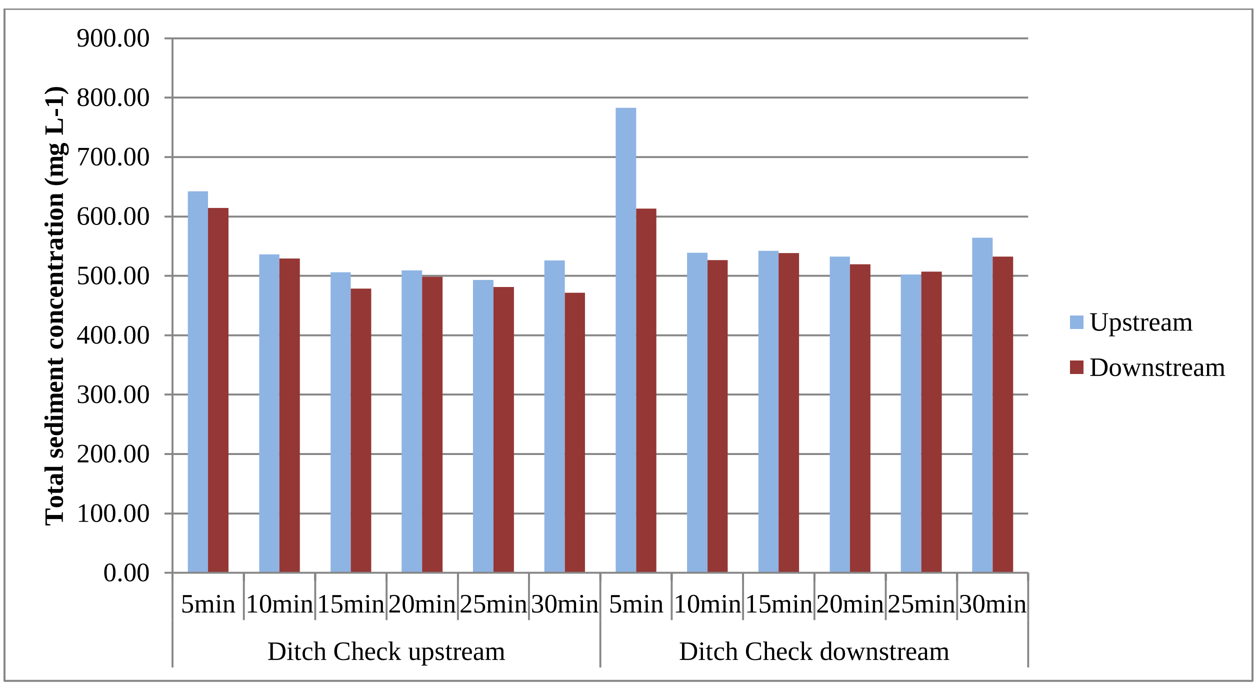


Figure A.24. Replication 3 TSC values for GeoRidge under 5 L s^{-1} flow rate.

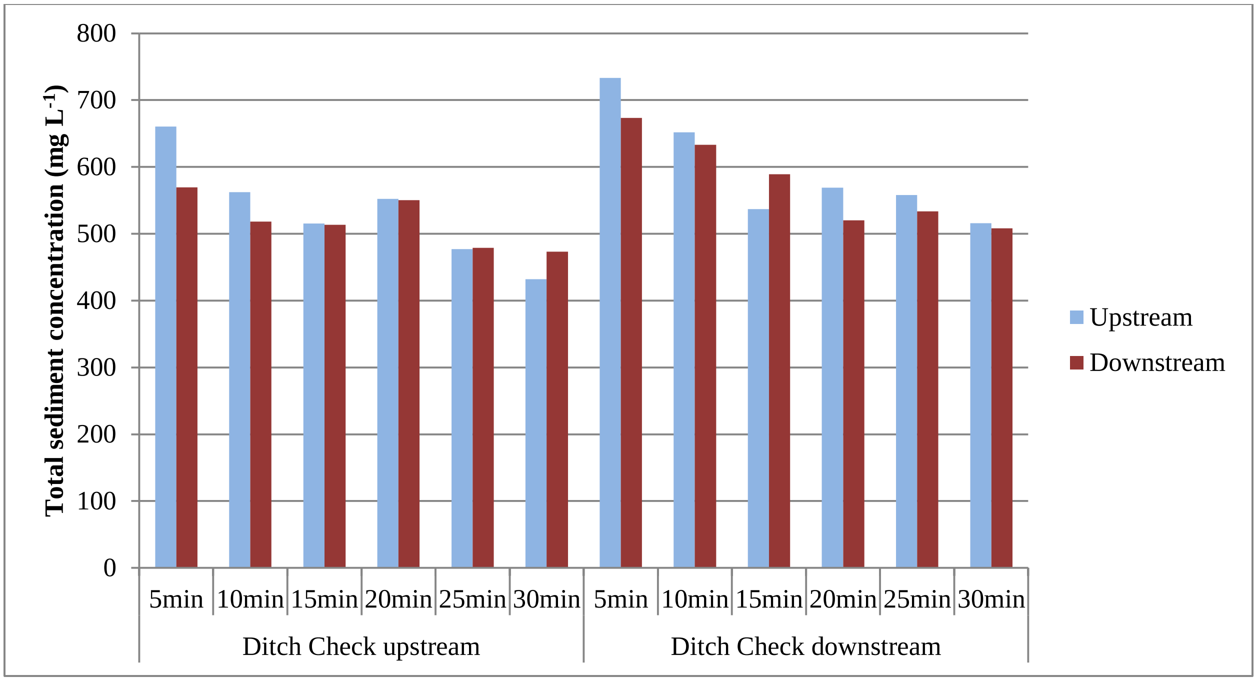


Figure A.25. Replication 1 TSC values for Sediment Log under 5 L s^{-1} flow rate.

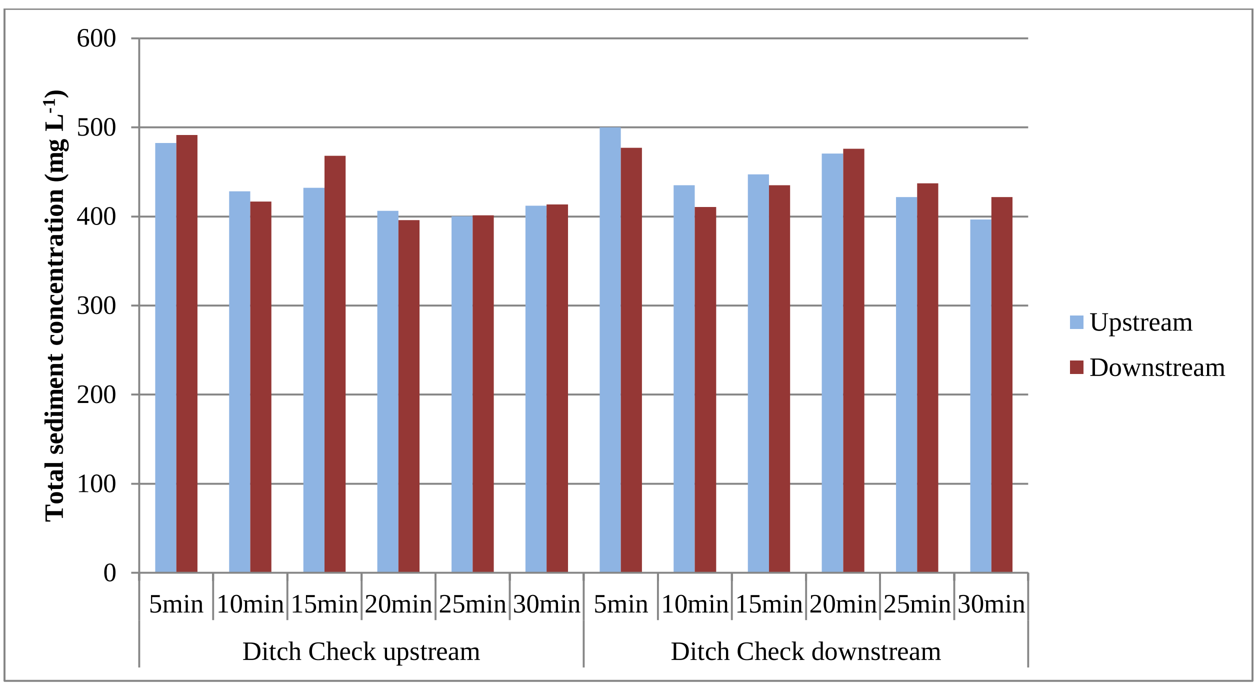


Figure A.26. Replication 1 TSC values for Sediment Log under 5 L s^{-1} flow rate.

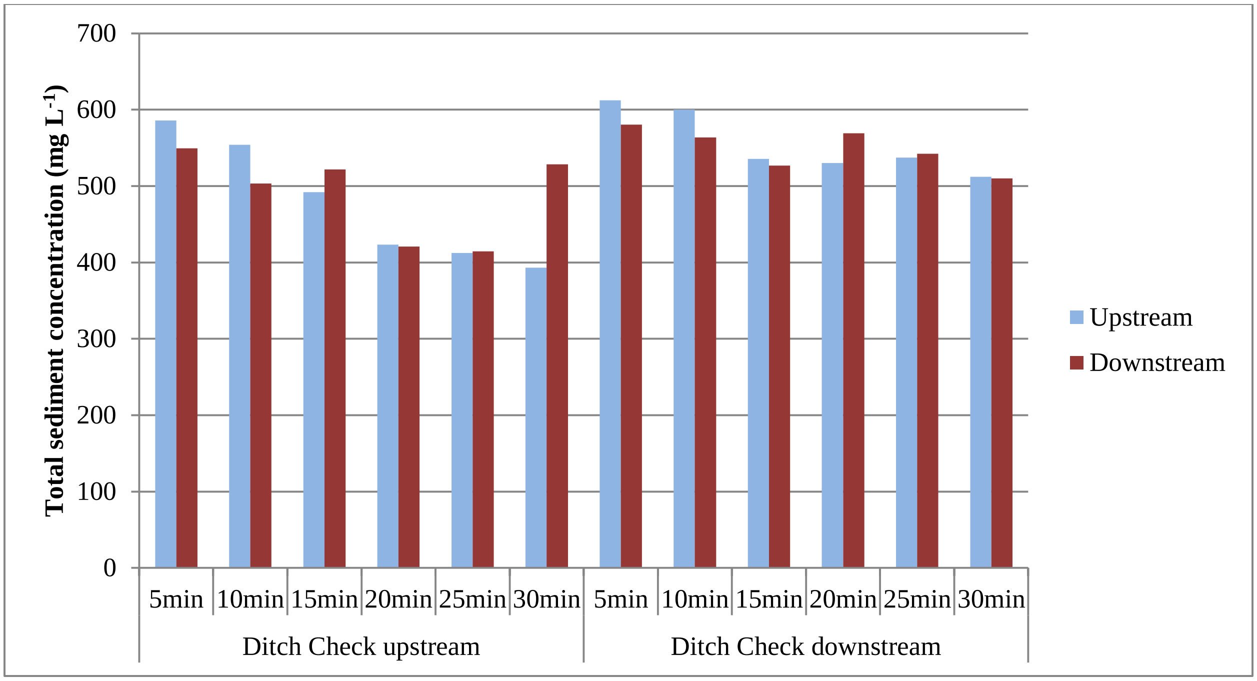
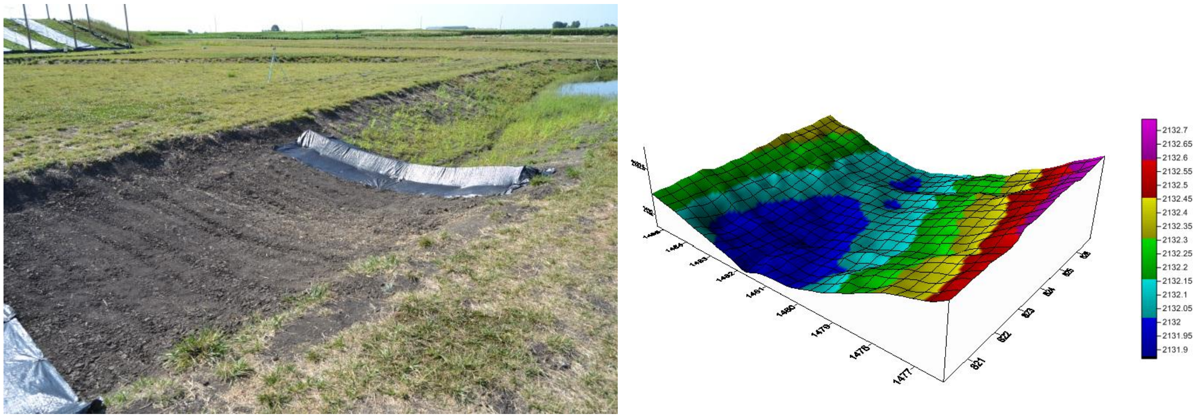


Figure A.27. Replication 1 TSC values for Sediment Log under 5 L s^{-1} flow rate.

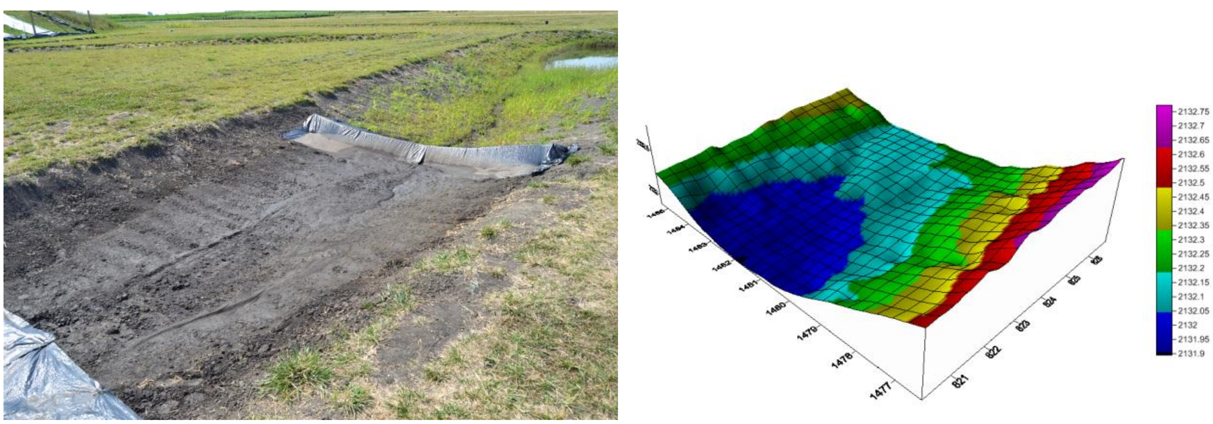
APPENDIX B

ADDITIONAL SURFACE SCANS



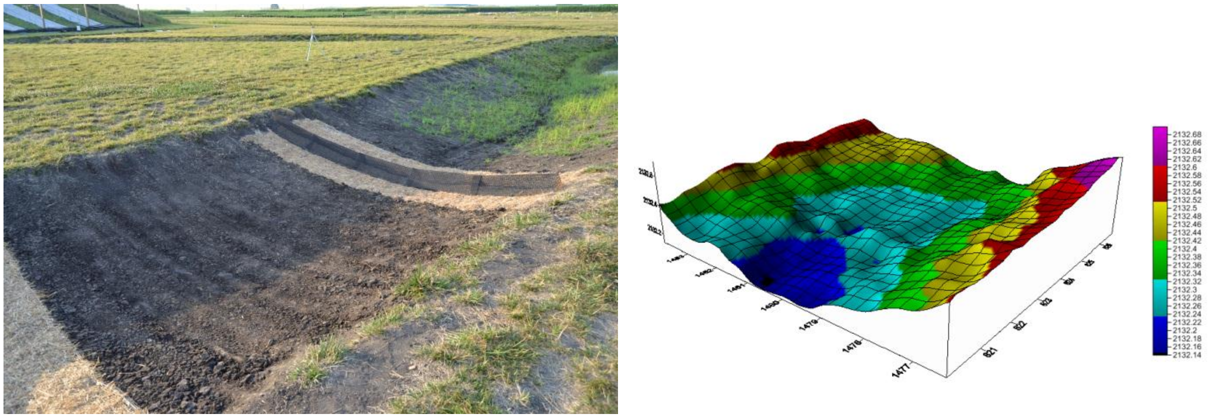
(a) (b)

Figure B.1. (a) Photograph of downstream Triangular Silt Dike prior to testing under the 7.5 L s^{-1} flow rate. (b) Associated scanned profile for front side of downstream Triangular Silt Dike.



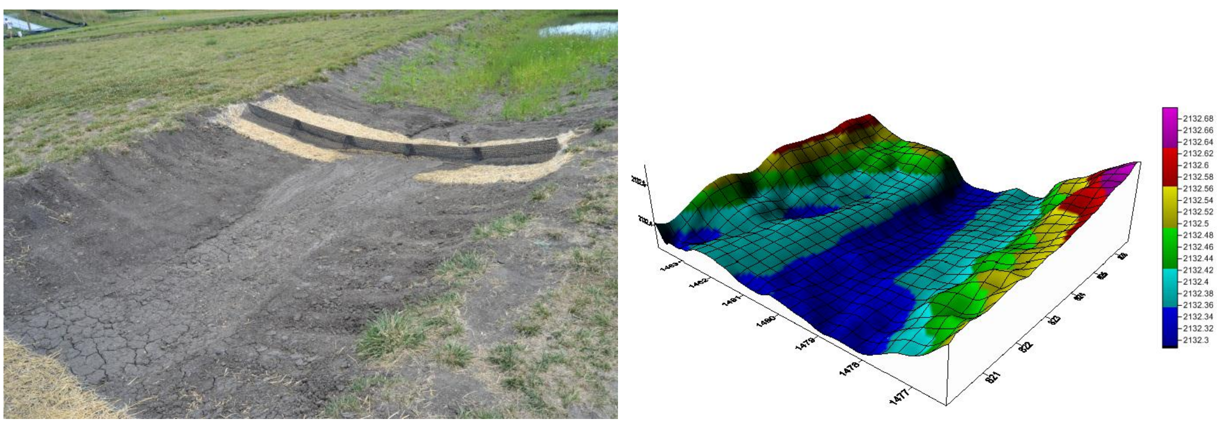
(a) (b)

Figure B.2. (a) Photograph of downstream Triangular Silt Dike after testing under the 7.5 L s-1 flow rate. (b) Associated scanned profile for front side of downstream Triangular Silt Dike.



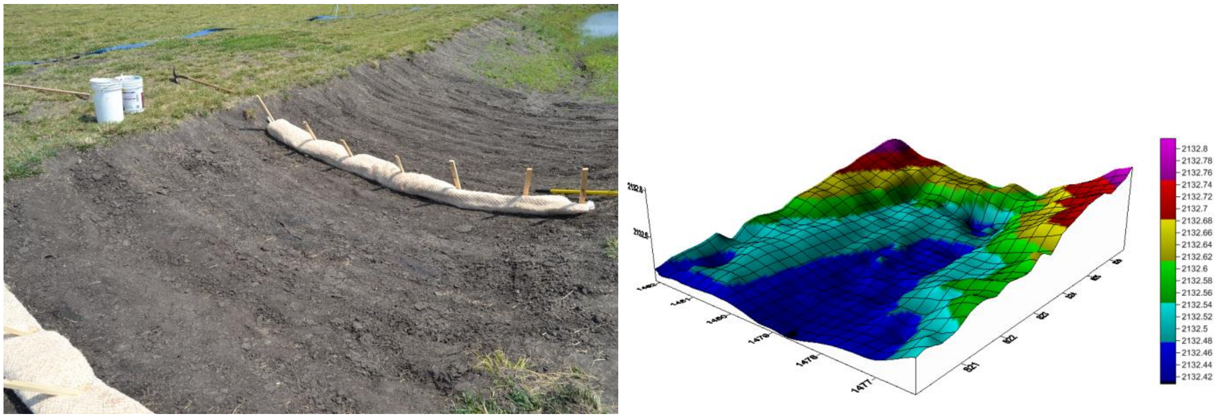
(a) **(b)**

Figure B.3. (a) Photograph of downstream GeoRidge prior to testing under the 7.5 L s^{-1} flow rate. (b) Associated scanned profile for front side of downstream GeoRidge.



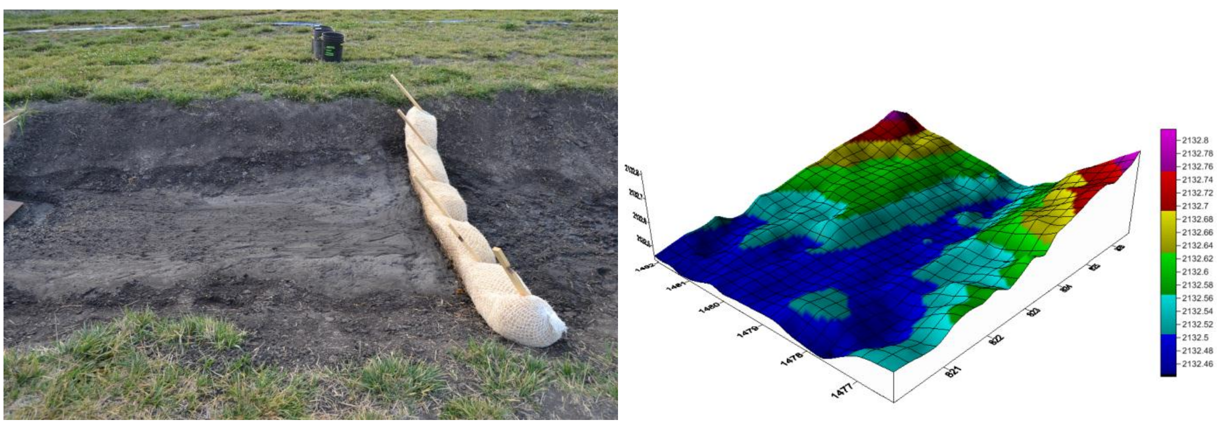
(a) **(b)**

Figure B.4. (a) Photograph of downstream GeoRidge after testing under the 7.5 L s^{-1} flow rate. (b) Associated scanned profile for front side of downstream GeoRidge.



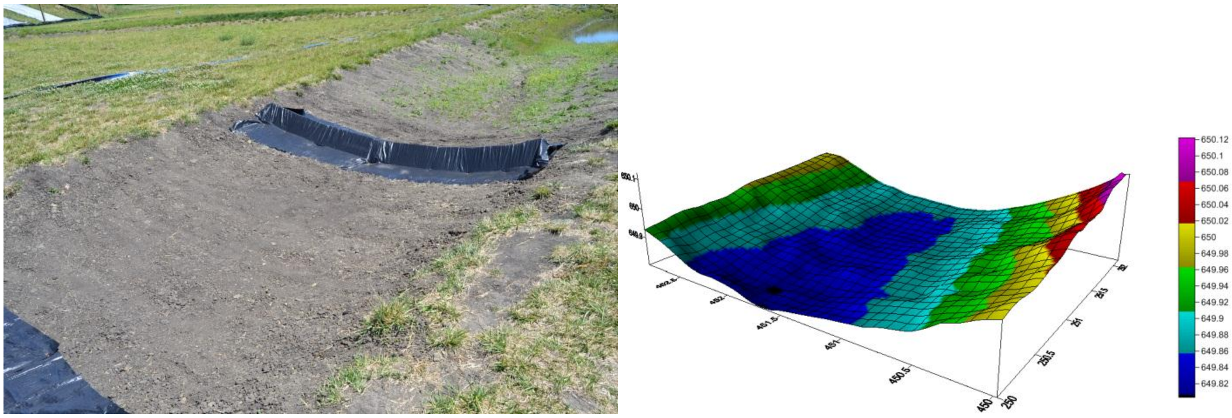
(a) (b)

Figure B.5. (a) Photograph of downstream Sediment Log prior to testing under the 7.5 L s^{-1} flow rate. (b) Associated scanned profile for front side of downstream Sediment Log.



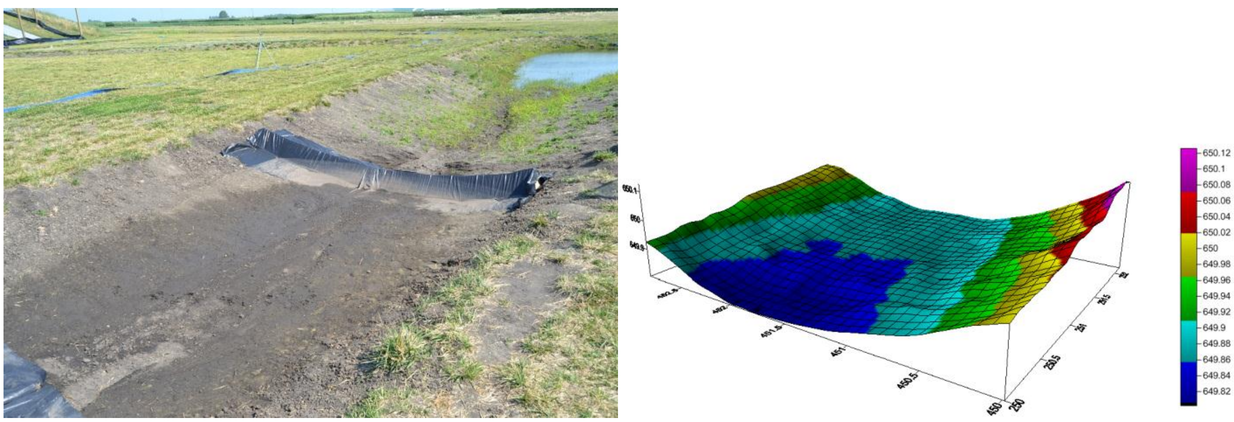
(a) (b)

Figure B.6. (a) Photograph of downstream Sediment Log after testing under the 7.5 L s^{-1} flow rate. (b) Associated scanned profile for front side of downstream Sediment Log.



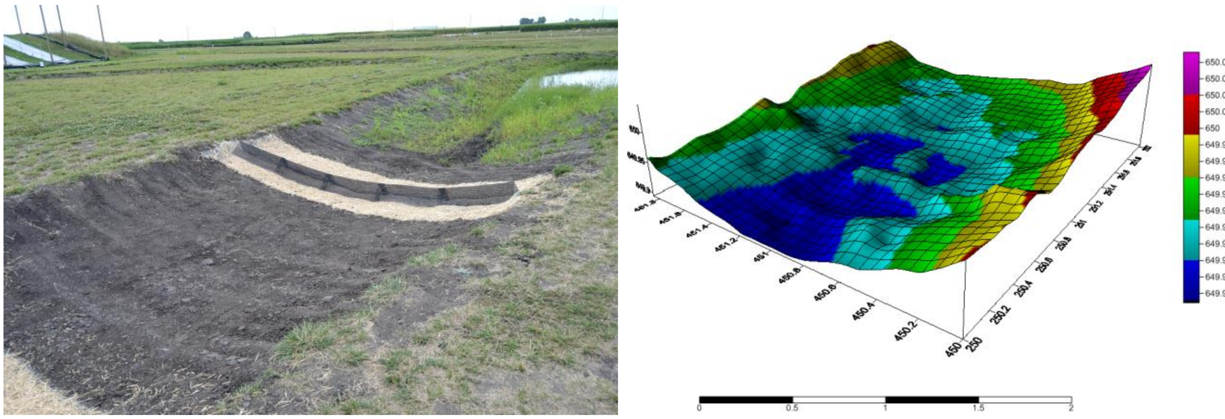
(a) (b)

Figure B.7. (a) Photograph of downstream Triangular Silt Dike prior to testing under the 5 L s^{-1} flow rate. (b) Associated scanned profile for front side of downstream Triangular Silt Dike.



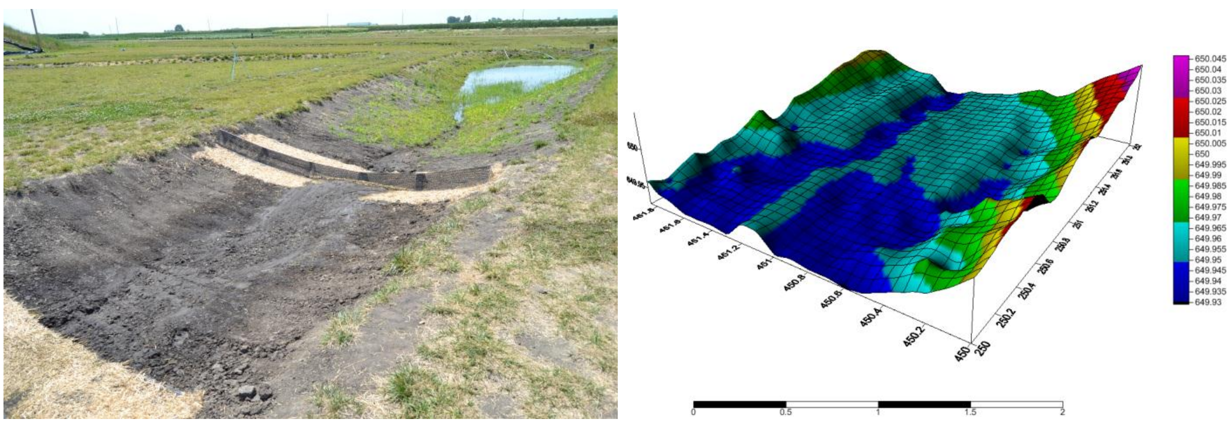
(a) (b)

Figure B.8. (a) Photograph of downstream Triangular Silt Dike after testing under the 5 L s^{-1} flow rate. (b) Associated scanned profile for front side of downstream Triangular Silt Dike.



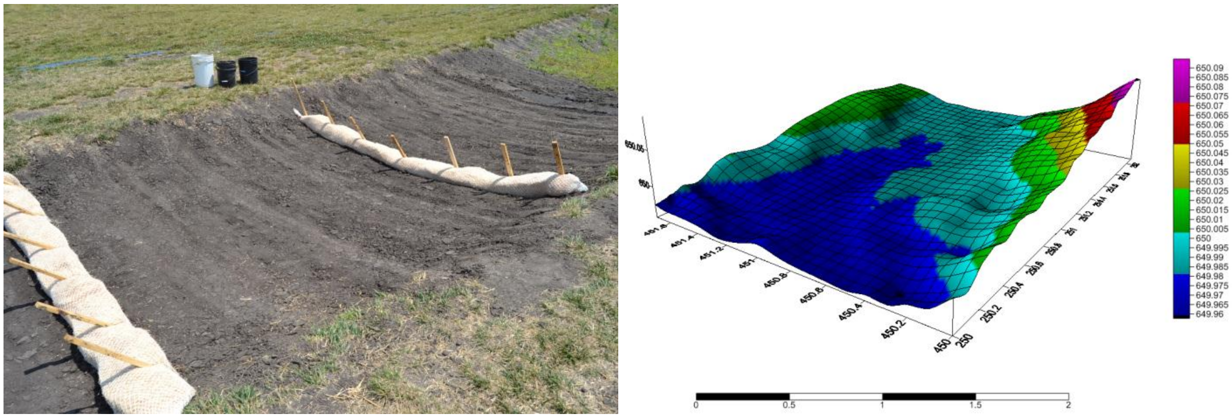
(a) (b)

Figure B.9. (a) Photograph of downstream GeoRidge prior to testing under the 5 L s^{-1} flow rate. (b) Associated scanned profile for front side of downstream GeoRidge.



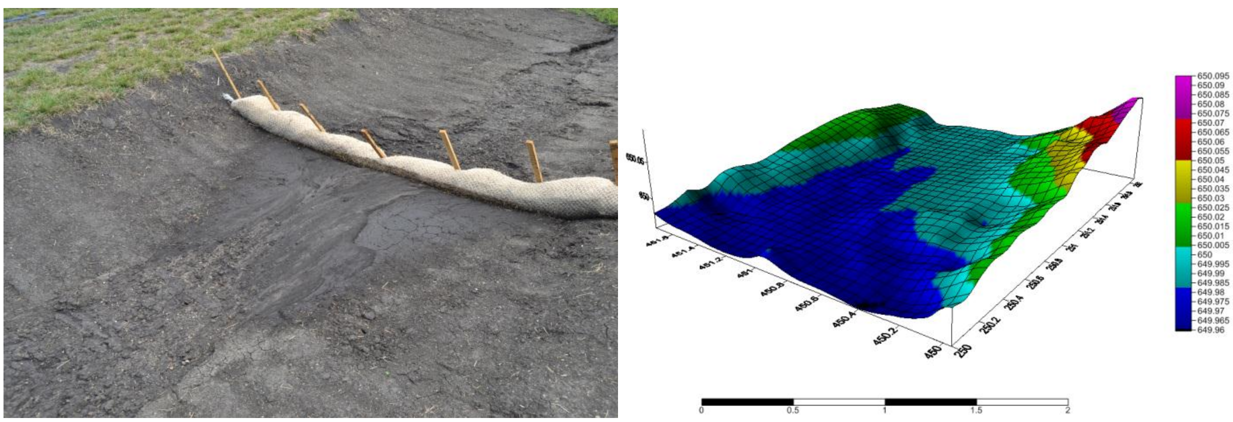
(a) (b)

Figure B.10. (a) Photograph of downstream GeoRidge after testing under the 5 L s^{-1} flow rate. (b) Associated scanned profile for front side of downstream GeoRidge.



(a) (b)

Figure B.11. (a) Photograph of downstream Sediment Log prior to testing under the 5 L s^{-1} flow rate. (b) Associated scanned profile for front side of downstream Sediment Log.



(a) (b)

Figure B.12. (a) Photograph of downstream Sediment Log after testing under the 5 L s^{-1} flow rate. (b) Associated scanned profile for front side of downstream Sediment Log.